

NASA Technical Memorandum 85126

NASA-TM-85126 19830004432

NASA Geodynamics Program: Annual Report for 1981

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

Geodynamics Program Office

August 1982

NASA

NASA Technical Memorandum 85126

**NASA Geodynamics Program:
Annual Report for 1981**

Geodynamics Program Office
Office of Space Science and Applications
Washington, DC 20546



**Scientific and Technical
Information Branch**

1982

Table of Contents

| | | |
|------|--|----|
| I. | <u>Introduction</u> | 1 |
| | Highlights and Achievements for 1981 | 1 |
| II. | <u>Geodynamics Program Objectives, Elements, and Funding</u> .. | 3 |
| | A. Objectives | 3 |
| | B. Program Elements | 3 |
| | 1. Global Earth Structure and Dynamics | 3 |
| | 2. Regional Crustal Deformation Modeling | 3 |
| | 3. Lithosphere Structure and Evolution | 4 |
| | 4. Geopotential Field Models | 4 |
| | 5. Advanced Geodynamics Instruments and Missions .. | 4 |
| | C. Program Funding | 5 |
| III. | <u>Program Coordination</u> | 6 |
| | A. National Coordination | 6 |
| | B. International Coordination | 6 |
| IV. | <u>Crustal Dynamics Project</u> | 9 |
| | A. Measurements | 9 |
| | B. Investigations | 10 |
| | C. VLBI System Development | 10 |
| | D. Laser System Development | 12 |
| | E. System Validation and Intercomparison | 13 |
| | F. Data Base | 14 |
| V. | <u>Research Status and Results</u> | 15 |
| | A. Global Earth Structure and Dynamics | 15 |
| | B. Crustal Motion and Regional Crustal Deformation Modeling | 16 |
| | C. Geopotential Field Models | 16 |
| VI. | <u>Advanced Studies and Missions</u> | 17 |
| | A. Gravity and Magnetic Field Measurements | 17 |
| | B. Rapid Surveys for Local Deformation | 18 |
| | C. Time Transfer | 18 |

| | | |
|------------------------------|---|----|
| <u>Table 1:</u> | Geodynamics Program Funding FY 1980-1983 | 19 |
| <u>Appendix 1:</u> | Crustal Dynamics Project Investigators and Investigations | 20 |
| <u>Appendix 2:</u> | Investigations Selected in Response to the Applications Notice, 1981 | 25 |
| <u>Appendix 3:</u> | Glossary of Acronyms and Abbreviations | 27 |
| <u>Appendix 4:</u> | Publications on Research Supported by the NASA Geodynamics Program | 29 |
| <u>References</u> | | 41 |
| <u>Figure Captions</u> | | 42 |

I. INTRODUCTION

This document is the third annual report of the NASA Geodynamics Program. Its purpose is to inform interested agencies and individuals of the status, progress, and plans of the program. The intention of the Geodynamics Program Office is to issue similar reports each year.

The first of these annual reports (NASA, 1980) contained a section of background and historical information, to bring the reader up to 1979 since the beginning of the program as the National Geodetic Satellite Program. The second annual report (NASA, 1981a) highlighted the progress in instrumentation development and theoretical research, and the preparation for initiation of crustal motion measurements in the western U.S. This report also included a list of publications of research results supported by the Program.

This, the third annual report of the Program, reflects the considerable progress made in 1981, both in achieving improved measurement precision and in establishing the foundation for the acquisition and analysis of scientific data.

The investigations and investigators in the Geodynamics Program and the publications related to the Program are listed in the appendices.

HIGHLIGHTS AND ACHIEVEMENTS OF 1981

The NASA program advanced broadly in 1981 towards the objectives of understanding the earth's crustal motion, deformation and rotation dynamics; and of achieving improved models of the earth's gravity and magnetic fields.

The principal highlights of 1981 were:

1. The selection of 57 Crustal Dynamics Project Investigations, including 16 from other countries.
2. The initiation of baseline measurements in the western U.S. from 23 sites, using mobile VLBI and laser ranging stations.
3. The analysis of over 40 VLBI determinations of the 3,928 km baseline between Westford, MA, and Owens Valley, CA. Over a five year period there is no detectable change in baseline length between these stations within ± 0.5 cm/yr. The individual measurements had a precision of better than ± 3 cm rms.
4. The measurement of baselines between American VLBI stations (Westford, MA; Ft. Davis, TX; and Owens Valley, CA) and European VLBI stations (Onsala, Sweden; Bonn, West Germany; Chilbolton, England) to a precision of 3 cm. In addition, the global

laser network operated throughout the year for repeated measurements of baselines between stations on the North American, Pacific, South American, Australian, and Eurasian Plates. Regular determinations of five-day values of polar motion and length of day were also made.

5. The Polaris VLBI station at Westford, MA, was completed and NOAA initiated routine measurements of polar motion and UT. The results to date have a repeatability of 3 milliarseconds in polar motion and 70 microseconds in UT1.

6. Very good agreement was demonstrated between polar motion determinations from VLBI, satellite laser ranging, and lunar laser ranging. The differences between BIH and these three systems were found to be real.

7. A very strong correlation was demonstrated between the changes in the measured length of day and the changes in atmospheric angular momentum computed from global weather data.

8. Sub-centimeter laser ranging precision was demonstrated, and procurement was initiated to upgrade Moblas 4-8 to this level of precision.

9. A new gravity field model for LAGEOS was developed, which has improved the precision of baselines and PM/UT by a factor of two.

10. Tracking accuracies of better than 0.3 micron/sec were demonstrated in the laboratory for application to satellite-to-satellite tracking measurements of the earth's gravity field.

11. The first vector field models of the earth's magnetic field and crustal anomalies were developed.

II. GEODYNAMICS PROGRAM OBJECTIVES, ELEMENTS, AND FUNDING

A. OBJECTIVES

The objectives of the NASA Geodynamics Program are: (1) to contribute to the understanding of the solid earth, in particular the long-term crustal processes associated with natural hazards and resources, and the structure and internal composition of the earth; (2) to develop models of the earth's gravity and magnetic fields for multidisciplinary science and applications needs; and (3) to facilitate the establishment of new geodynamics measurement services requiring precise position determination.

Achievement of these objectives depends on the development, demonstration, and use of techniques for measuring crustal motion and deformation and on improved measurement of the earth's gravity and magnetic fields. The program includes research in modeling of crustal processes, earth rotational dynamics, and geopotential fields; this research is a necessary part of the program. Studies of new instrumentation and space mission concepts are also supported.

The principal space techniques now available for precise measurements of crustal motion and deformation, polar motion, and earth rotation are very long baseline microwave interferometry (VLBI) using signals from extragalactic radio sources or from satellites, and laser ranging to the moon and to man-made satellites such as Lageos. The VLBI and satellite laser ranging methods employ both fixed and mobile stations.

In 1981 the Office of Space and Terrestrial Applications and the Office of Space Science were recombined into the Office of Space Science and Applications; however, the scope and objectives of the NASA Geodynamics Program (which was relocated to the Earth and Planetary Exploration Division within the newly formed OSSA) were not affected by this reorganization.

B. PROGRAM ELEMENTS

1. Global Earth Structure and Dynamics. The objective is to improve our understanding of the dynamics of the earth by development of models of polar motion and earth rotation, global plate motion, and the dynamics of the core; and to improve our understanding of the global structure of the earth, including its crustal magnetization, gravity field, and the evolution of the crust and lithosphere. Formulation of a standard dynamic earth model will be attempted under this program element.

2. Regional Crustal Deformation Modeling. The objective of this element is to conduct modeling studies of crustal deformation in various tectonic settings. These studies are needed to assist in determining what measurements are required and to provide a proper perspective for analysis of data acquired by the

Crustal Dynamics Project. The main types of models involved are earthquake mechanism, accumulation of stress and strain, and vertical motion.

3. Lithosphere Structure and Evolution. In this element, studies are conducted which are related to the processes which have formed the lithosphere, in order to gain a better understanding of the dynamic mechanisms that are active at present. Under this program, element models are being developed that relate to the current state, origin, evolution, and dynamics of the lithosphere. The objective is to derive plate-driving mechanisms, including mantle convection, to explain current plate motion measurements. Emphasis is placed on understanding the nature of subduction and collision zones and lithosphere/mantle rheology.

4. Geopotential Field Models. The objectives of this element are to develop gravity and magnetic field models, to investigate data analysis techniques and software systems, and to support the Non-Renewable Resources and Ocean Research Programs as well as other elements of the Geodynamics Program. Emphasis is placed on use of satellite altimetry and determination of the maximum resolution that can be achieved in the gravity field analysis with existing data. Magnetic field models (including secular variation) are developed in this area of the program. The development of a data base for ancillary information required for geodynamics investigations, such as gravity anomalies, topography, and bathymetry, is maintained under this element.

5. Advanced Geodynamics Instruments and Missions. These studies support the development of new methods for making geodynamics measurements using space systems and techniques and the development of advanced space mission concepts.

These program elements are supported through three principal activities:

a. A Crustal Dynamics Project (CDP) which is managed by the Goddard Space Flight Center, assisted by JPL. The CDP is responsible for the development of laser and VLBI systems, the acquisition and processing of data, and the analysis of these data by approved Principal Investigators.

b. A NASA Laser Network which is managed for the Geodynamics Program by the Office of Space Tracking and Data Systems. The responsibility for the Network is at GSFC and includes operation of Moblas and SAO lasers and coordination of cooperating laser systems in other countries.

c. A research and technique development program which selects and funds theoretical research and advanced systems and missions work both at NASA Centers and at universities.

C. PROGRAM FUNDING

Funding for the NASA Geodynamics Program from all sources for FY 1980-82 and planned funding for FY 1983 is shown in Table 1. Overall funding for FY 1982 and 1983 is 23% less than funding levels required to continue planned program activities. To accommodate these budgetary limitations, it was necessary to: (1) delay several activities planned by the CDP; (2) extend the CDP by two years from a completion date of 1986 to 1988; and (3) reduce all laser ranging observations from two shifts (16 hours per day, five days per week) to one shift (eight hours per day, five days per week).

Work relating to the Magnetic Field Satellite (Magsat) Mission will be completed in FY 1983. Additional magnetic field work in FY 1983 will be funded either under the Geodynamics RTD or from other sources.

In Fiscal Years 1980-1982 the Geopotential Research Mission (GRM) studies were supported by both the Geodynamics RTD and Earth and Planetary Exploration Division Advanced Studies funds.

III. PROGRAM COORDINATION

The study of crustal deformation and earth dynamics has engendered broad interest on a national and international scale, because of its implications for understanding earthquakes and the emplacement of resources, its influence on geodetic surveying, and because of what it can tell us about the internal structure and dynamics of the earth. Considering the global nature of the solid earth sciences and the importance of both the measurement of plate motion and the observation of regional deformation under both similar and different tectonic settings, the involvement of other countries is a vital aspect of achieving the NASA program objectives. Consequently, the NASA program has from its beginning stressed coordination of observing systems and the transfer of advanced technologies to operational entities in the U.S. and to other countries.

A. NATIONAL COORDINATION

At the national level, the NASA Program is coordinated through an interagency agreement involving NASA, NOAA, USGS, DMA and NSF. This Agreement, concluded in September 1980, outlined the roles of these U.S. federal agencies in the application of space technology to crustal dynamics and earthquake research. The Agreement established both The Interagency Coordinating Committee for Geodynamics (ICCG) and a Program Review Board (PRB). Several meetings of the ICCG were held in 1981 to approve the selection of sites for mobile systems, to consider proposals submitted in response to the NASA Announcement of Opportunity, and to formulate plans for the transfer of system technologies. As stipulated by the Agreement, the PRB met in July 1981 to evaluate the interagency programs and plans.

A highlight in 1981 was the formulation by the ICCG and the approval by the PRB of a plan for the establishment of operational geodetic services using space technologies (ICCG, 1981).

B. INTERNATIONAL COORDINATION

In response to the NASA Announcement of Opportunity for Crustal Dynamics and Earthquake Research, investigations were approved for scientists from France, England, Germany, Sweden, Spain, Switzerland, Canada, Venezuela, New Zealand, Australia, Chile, and The People's Republic of China (PRC). By the end of 1981, proposals were also received from Peru and Bolivia; these proposals are being reviewed.

An agreement was initiated with The French Centre National d'Etudes Spatiales (CNES) for installation of a Moblas facility in the Society Islands in the Pacific. Negotiations were also begun for locating a Moblas station at Mazatlan, Mexico, and for

loan of an SAO laser to The Italian Consiglio Nazionale delle Ricerche (CNR). The SAO laser is to be installed by CNR and operated at their expense. The agreement with CNR also initiates studies of joint NASA/CNR development and launch of a second Lageos satellite, and NASA technical assistance in the development of mobile VLBI and laser stations.

The most important international development in 1981 was the progress made by other countries in establishing space geodynamics programs similar to the NASA Geodynamics Program. New laser ranging and VLBI equipment is being constructed or planned in Japan, The Netherlands, The Federal Republic of Germany, Italy, England, Australia, People's Republic of China, Switzerland, and Austria. As a result of this activity, the International Association of Geodesy (part of the International Union of Geodesy and Geophysics) established jointly with COSPAR a Commission on International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG). CSTG has held several meetings, and has requested approval for establishment of a subcommission to coordinate programs using mobile VLBI and laser ranging stations.

Many of the European Crustal Dynamics Investigators have formed an informal consortium ("Wegener") to establish and coordinate a European program of crustal deformation measurements using the mobile laser ranging facilities now under development by the Delft University of Technology (The Netherlands) and the Institut für Angewandte Geodäsie (Federal Republic of Germany). NASA intends to participate in this program by positioning one of its transportable lasers in the Eastern Mediterranean as part of the observational campaign in 1985 (approximate date), and the developers of the European transportable lasers also intend to extend their participation in the NASA Geodynamics Program at a later date by operating their equipment in the Western Hemisphere.

The Ad Hoc Committee of Experts on Earthquake Prediction, part of the Council of Europe, is preparing a plan for a coordinated European program of earthquake prediction research; the plan is to be submitted to the Council of Ministers of the Council of Europe in December 1982. The activities of the Wegener Consortium are at the present time included in the draft program plan. Discussions were initiated in 1981 between the Wegener Consortium chairman, the Council of Europe, the European Space Agency, and NASA, aimed at arriving at an agreement concerning the use of transportable lasers for crustal deformation measurements in the Eastern Mediterranean area.

A new satellite laser ranging observatory is being built at Simosato, Japan, under the auspices of the Japanese Hydrographic Department, Maritime Safety Agency. JHD is also planning to construct a mobile laser ranging facility as part of its GS-1 Geodetic Satellite Mission. NASA and JHD are now discussing an agreement covering exchange of satellite laser data and technical information on mobile laser systems.

A satellite laser ranging observatory is nearing completion at the Institute of Seismology, State Seismological Bureau, at Wuhan in the central People's Republic of China. Discussions are being held between SSB and NASA concerning a laser data exchange agreement.

A VLBI experiment was conducted in 1981 between Bonn University's Effelsberg radio observatory and a smaller radio antenna at the Shanghai Observatory, People's Republic of China. The experiment will be repeated in 1982. Shanghai Observatory is constructing a 25m geodetic VLBI radio observatory, which should be in operation in 1985. Shanghai Observatory and NASA are considering extending the existing laser data exchange agreement to cover joint experiments and data using the new Shanghai VLBI facility.

VLBI experiments are planned for 1984 using NASA-operated VLBI observatories and the 26m radio telescope operated by the Japanese Radio Research Laboratories (RRL), Ministry of Posts and Telecommunications, at Kashima, Japan. NASA and RRL are considering extension of the existing agreement on the 1984 experiments to include a regular program of observations at Kashima and NASA stations throughout the lifetime of the Crustal Dynamics Project.

In 1981 the International Council of Scientific Unions (ICU), at the request of the International Union of Geodesy and Geophysics (IUGG) and the International Union of Geological Sciences (IUGS), established a ten-year program on Dynamics and Evolution of the Lithosphere. The new program, a broadening and extension of the International Geodynamics Project, is coordinated by the Inter-Union Commission on the Lithosphere (ICL). At organizational meetings of the Commission in 1980 and 1981, working groups and coordinating committees were established on seventeen different aspects of modern research in geodynamics. The NASA activities in applying space technology to research in geodynamics are essential in accomplishing the objectives of the program. Two of the ICL bodies (Working Group #1, Recent Plate Movements and Deformation; and Coordinating Committee #1, Environmental Geology and Geophysics) are making use of the results of the NASA program, and include members who are also principal investigators in the NASA program or who are directly involved with interpretation of the NASA results.

IV. CRUSTAL DYNAMICS PROJECT

A. MEASUREMENTS

As part of the western U.S. regional deformation studies, mobile VLBI operations were conducted with base stations at Goldstone (DSS-13), CA; Owens Valley (OVRO), CA; and Ft. Davis (HRAS), TX. Baselines were measured between the base stations and the following sites occupied by MV-2 or MV-1: Pasadena, Palos Verdes, Pearblossom, La Jolla, Monument Peak, Pinyon Flat, Gorman, Santa Paula, Presidio, Pt. Reyes, Vacaville, Ft. Ord, and Vandenberg AFB, all in California, and Yuma, AZ. (Figure 1)

The TLRS operations in the western U.S. used base stations at Platteville, CO, Quincy, CA, and Monument Peak, CA. Baselines were measured from the base stations to TLRS sites at Bear Lake, UT; Vernal, UT; Owens Valley, CA; and Otay Mountain, CA.

For studies of plate deformation, VLBI measurements were made between Westford, MA; Owens Valley, CA; and Ft. Davis, TX. These show baseline length changes of 0 ± 0.5 cm/yr. These repeated individual VLBI measurements had a precision of better than ± 3 cm rms.

In cooperation with other federal agencies, an agreement was reached on the establishment by NOAA of a National Crustal Motion Network (NCMN) beginning in 1984. This Network (Figure 2) includes all of the U.S. sites selected for the CDP plus other sites of interest to NOAA. The Network will be monitored by NOAA using VLBI equipment transferred from NASA.

For studies of plate motion, baselines were measured using fixed VLBI stations in the U.S. (Westford, MA; Ft. Davis, TX; and Owens Valley, CA) and Europe (Onsala, Sweden; Bonn, Federal Republic of Germany; and Chilbolton, England); these measurements had a precision of ± 3 cm (Figure 3). The global laser network (Figure 4) operated throughout the year for repeated measurements of baselines between sites in North America and the Pacific, Pacific and South America, Pacific and Australia, North America and South America, and North America and Europe. Regular determinations of five-day values of polar motion and length of day were also made.

The Polaris station at Westford, MA, was completed by NASA, under contract to NOAA, and was accepted by NOAA in September 1981. By mid-year, Polaris (Figure 5) started routine measurements of polar motion and UT using two stations. The results to date have repeatability of 3 milli-arseconds in polar motion and 70 microseconds in UT1.

Laser ranging data using Lageos has been acquired from a dozen or more stations in the U.S. and abroad almost continuously since early 1976. Polar motion measurements derived from these data for the period of May 1976 to August 1981 (Figure 6) show the damping of the Chandler wobble during the past few years.

The Project continued lunar laser ranging measurements of the length of day using the 107" telescope at McDonald Observatory (Fort Davis, TX). Very good agreement was demonstrated between polar motion determinations from VLBI, satellite laser ranging and lunar ranging. Significant differences from BIH were found.

B. INVESTIGATIONS

In response to the NASA Announcement of Opportunity for Crustal Dynamics and Earthquake Research, 57 investigations were selected to use data acquired by the CDP. These investigations include research in regional crustal deformation, plate motion, earth rotational dynamics, and system performance evaluation and improvement. A list of the approved investigators, their affiliation, and a brief title of the investigation is included as Appendix 1.

At the first meeting of the selected investigators in September 1981, discussions were initiated of specific measurement sites in the U.S., Caribbean, Alaska, and Europe. This discussion was continued through a series of meetings in 1981 to resolve experiment differences and to confirm a set of mutually acceptable sites.

C. VLBI SYSTEM DEVELOPMENT

In 1981, MV-1 and MV-2 antenna and associated electronics vans were equipped with a Mark-III data system. These systems, operating in conjunction with compatible base stations at Owens Valley Radio Observatory, Goldstone, and Fort Davis (Texas) occupied a total of 14 sites in 1981.

The NASA STDN station at Mojave, California, was transferred to the CDP, and implementation of VLBI capability there was initiated. This station will be developed as a dedicated geodetic VLBI base station for western U.S. regional studies and will replace Project use of the DSS-13 antenna at Goldstone, CA.

Work continued in the development of MV-3, the first mobile VLBI system specifically designed for geodetic measurements. Both the Mojave station and the MV-3 are to be in operation in early 1983.

To improve the efficiency and use of VLBI, several R&D activities were conducted. These included:

(1) Studies of tape recording methods which would produce at least an order of magnitude improvement in bit density on the Mark-III data tapes which, in turn, will lead to a significant reduction in cost and logistics problems during data acquisition and correlation.

(2) Development of three-baseline correlation to reduce processing time.

(3) Development of analytic techniques involving baseline triangular closure. One technique uses simultaneous observations over a network of stations; if one baseline is weak due to the use of small antennas, the missing observations are inferred by instantaneous delay closure through larger "base" stations. These results showed that using this procedure there is no significant loss in performance, and that station site occupations might be saved by improved sensitivity. A related technique is to give one station two different names in the analysis; the covariance analysis results are tested by examining closure on the resulting zero-length baseline.

Improvements in VLBI analytic models were made. These included new formulations of the raw VLBI time-delay observable, with effects of special and general relativity. This analysis showed that in addition to terms in the existing models, gravitational bending of light by Jupiter should be incorporated for sources near the ecliptic, and that a refraction-like bending of light by the earth's gravitation field should be included.

The J2000 IAU and MERIT definitions were implemented into the GSFC CALC/SOLVE analysis software. The new formulations show 5-10 milliarcsecond repeatability between disjoint data sets.

Studies were also conducted of a radio reference frame for accurate measurement of baselines using VLBI. This study involves fitting 742 parameters for 1971-1980 VLBI data, including station location, solid earth tides, earth orientation, precession, source locations, clock offsets and rates, and properties of the troposphere. The rms residuals obtained were 0.3 psec/sec for delay rate and 0.5 nsec for delay.

Seven of the eight NASA water vapor radiometers (WVR) were installed at VLBI stations in 1981. The stations currently equipped with WVRs are Owens Valley, Goldstone, Fort Davis, Haystack/Westford, and the NASA MV-1 and MV-2 systems. Verification tests show that the WVRs are capable of making calibrations at the centimeter level; the most impressive results were obtained with WVRs on two antennas 7 km apart at the National Radio Astronomy Observatory's VLA facility in New Mexico, which measured interferometric phase fluctuations at the sub-centimeter level.

Studies of various effects on hydrogen maser frequency standards and the resultant propagation of errors into VLBI measurements show that improved analytic parameterization of clocks in terms of epoch, rate, and diurnal sinusoids improves the recovery

of geodetic parameters. It was found that with good environmental control of the masers, systematic errors are significantly reduced, and post-fit residuals for the entire VLBI system are similar in behavior to laboratory measurements of the masers themselves.

While it is generally agreed that VLBI has demonstrated precision at better than three centimeters; and the thrust is now to improve system precision to the one-centimeter level, results of detailed analysis of residual instrumental effects and ionospheric calibrations show that the formal standard errors based on multi-parameter covariance analysis should be scaled upward by factors of 2-3 to account for non-random error sources.

Results of studies of ionospheric effects indicate that if only X-band (8.4 GHz) data are used at times of solar maximum, errors up to 20 cm in baseline length on long baselines could result. Similar results from the mobile VLBI systems on short baselines showed that S-band (2.3 GHz) daytime data was seriously corrupted by the ionosphere and should not presently be used for geodetic analysis. However, nighttime S-band data, as well as X-band data for both day and night, can probably be trusted at the 5-10 cm level on baselines up to 400 km.

D. LASER SYSTEM DEVELOPMENT

In 1981, Moblas-7 (with an upgraded Sylvania laser) replaced the aging Stalas in the GSFC laser tracking network. Moblas stations were established at Platteville, CO; Monument Peak, CA; and at a new location at Quincy, CA. The satellite laser ranging capability at Haleakala, HI, was improved, and after extensive collocation with Moblas-1 (which demonstrated the high precision of the improved system), the station was returned to operational status.

The TLRs-1 was placed into operation in early 1981. The first year of tracking with TLRs-1 showed good nighttime tracking of Lageos, but the daytime tracking capabilities of TLRs-1 need to be improved. Three items are being incorporated to improve daytime tracking: (a) better on-site integration; (b) installation of an 0.8 micron Fabry-Perot interference filter; and (c) software upgrading.

Work continued at GSFC on the development of TLRs-2, which is to be completed in 1982 and deployed to Easter Island in the Pacific. A Quantel laser has been obtained for this system.

In 1981, sub-centimeter precision ranging with a Quantel laser and an ITT detector was demonstrated using Moblas-4. Based on the test results, the Quantel laser has been selected for the upgrading of Moblas 5-8. Procurement for four additional Quantel lasers has been implemented. Work was also initiated in 1981 to improve the

SAO laser ranging systems, and studies of associated hardware improvements needed to enhance these lasers were continued. The upgrading was carried out at Mt. Hopkins, AZ, and will improve the range accuracy from 10 to 5 cm, increase the Lageos data rate from 8 to 30 ppm, and improve the daytime Lageos tracking capability. Initial tests show that the wavefront distribution is still a problem that must be solved before the system can be implemented. In 1982, it is planned to retrofit the SAO laser at Arequipa, Peru. Because of funding reductions, the operations of the SAO laser at Natal, Brazil, were terminated in October 1981. This laser will be retrofitted and given on indefinite loan to the Italian CNR. In February 1982, operation of the SAO laser at Orroval Valley, Australia, was also terminated because of funding limitations.

The McDonald Lunar Ranging Station (MLRS) was designed to range to both Lageos and the moon. This station, which is to replace the use of the 107" telescope in the McDonald Observatory, neared completion in 1981. Actual testing is planned to begin in early 1982.

In a related activity, contract negotiations were initiated between NASA and the National Mapping Division (Natmap) of the Australian Department of National Development and Energy for the modification and upgrade of the Lunar Laser Ranging Station at Orroval Valley, Australia. This station, which was provided by NASA to Natmap on an indefinite loan basis in 1974, is to be modified to range to Lageos (with 1.5 cm precision) and the lunar ranging precision improved to ± 5 cm. The new Natmap Laser Ranging Station (NLRS) is expected to be operational in late 1983 or early 1984.

Analysis by the University of Texas of the quantity and quality of the laser ranging data taken during the past few years shows that not enough worldwide data is being obtained to adequately determine the model parameters necessary for good orbit determination. In particular, there are large gaps in the data taken from Europe. As far as the quality of the data is concerned, the study indicated large diurnal variations. Investigations are underway to find the source of these anomalies.

E. SYSTEM VALIDATION AND INTERCOMPARISON

Intercomparison of VLBI systems with geodetically determined baselines were conducted in the late 1970's. These intercomparisons were later extended to include VLBI and laser systems (see NASA, 1980, and NASA, 1981, for historical accounts).

Intercomparison Session IV (October 1979 - March 1980) involved Moblas and VLBI stations at Westford, Fort Davis, Goldstone, and Owens Valley; Intercomparison Session V (October - December 1980) involved JPL, Owens Valley, and Goldstone. Baselines were determined independently by satellite laser ranging and VLBI. The baselines were compared between common points located at each site. The differences between SLR and VLBI measurements of seven baselines were found to average about 7 ± 3 cm (Figure 7).

F. DATA BASE

The CDP has established a data base system (NASA, 1981b) which will provide for ready access of investigators and other users of the data acquired by the CDP. Several types of information will be available to users in 1983 via remote terminals; these include the data sets provided by the SLR and VLBI Crustal Dynamics support groups, which include station coordinates, baseline lengths, polar motion, and length of day.

V. RESEARCH STATUS AND RESULTS

Additional results of research being conducted in the Geodynamics Program are described elsewhere in this report. In this section we summarize results presented at the Fourth Annual Conference on the NASA Geodynamics Program held at Goddard Space Flight Center in January 1982.

A. GLOBAL EARTH STRUCTURE AND DYNAMICS

Investigators are studying polar motion and earth rotation using data acquired by the Crustal Dynamics Project. VLBI determinations between observatories in the United States and Europe yielded baseline accuracies of 2-3 cm, polar motion to 2-3 milli-arcseconds, and UT1 to 20 microseconds during the MERIT short campaign in 1980. Differences between polar motion by VLBI and the BIH values amount to 4-9 m.

Several groups are studying the relationship between earth rotation rate and atmospheric angular momentum. Coupling between the solid earth and the oceans is being studied by Dickman in an attempt to explain the modulation of the Chandler wobble. Slade and others are studying the excitation of Chandler wobble by earthquakes, using a three-dimensional finite element program.

Gravitational and hydromagnetic coupling between the inner core, the outer core, and the mantle are being studied by Yoder. The torques caused by these types of coupling can affect the variation of the obliquity of the ecliptic and the 18.6 year forced nutation. Yoder proposes a highly deformable inner core to explain his observations. Kaula, Jarvis, Daly, and others are working on numerical studies of mantle convection.

Geophysical studies are being made using satellite-derived gravity field, geoid, and altimetry measurements. B. Marsh has shown that intermediate-wavelength gravity anomalies in the Pacific are explained by lithospheric structure, and that mantle effects are confined to low degree and order. Isostatically compensated topography can affect interpretation of geoid anomalies; Jones showed that the previous discrepancy between observed and calculated geoid anomalies in subduction zones can be explained on this basis. Hager and McAdoo have shown that internal flow and induced surface depression must be taken into account in calculating theoretical geoid anomalies. Different lithospheric cooling models can be discriminated using relationships between observed geoid height and crustal age; Sandwell is studying oceanic fracture zones from this point of view. Geoid anomalies are also being used by Roufousse to constrain models of lithospheric evolution and by A. J. Anderson to study crustal structure in Fennoscandia.

B. CRUSTAL MOTION AND REGIONAL CRUSTAL DEFORMATION MODELING

Global Lageos data and VLBI observations in the United States and between the U.S. and Europe do not yet show inter-station movements significantly different from zero. Mobile VLBI and laser ranging station measurements in California have also not yet detected crustal movements, although the correlation between apparent changes of VLBI station position and changes detected by ground-based geodetic measurements argue against systematic biases. Geodetic measurements in the Imperial Valley predict measurable crustal movements in that area, mainly across the southward extension of the San Andreas Fault System. Time-dependent post-seismic deformation, deformation at transform plate boundaries, intraplate deformation and stress, and intracrustal damping of geodetic displacements are being studied by several groups.

C. GEOPOTENTIAL FIELD MODELS

Two new gravity field models have been developed. One is Goddard Earth Model L1 (GEM-L1), which was developed by Lerch to improve Lageos orbit calculations and for use in long-wavelength sea-surface topography studies. The model has improved Lageos orbit errors from 1 meter to better than 50 cm; in calculating the field model, polar motion was also determined with an estimated precision of 8 cm. The other model is a 36x36 harmonic model derived by Reigber from surface gravity, satellite orbit perturbations, and GEOS-3 altimetry. These models differ in the nature and extent of mixing the similar gravity input parameters.

The Goddard Geodynamics Program (GEODYN) is being modified by Putney to adapt it to the new Cyber-205 computer at GSFC. The new machine is ten times the speed of the present IBM 360/95 system, and processes in a vector mode.

A magnetic field model, based entirely on Magsat data, has been adopted as the 1980 International Geomagnetic Reference Field (IGRF) by IAGA. Temporal variation analysis of magnetic observatory data were improved by Langel, by adding cubic terms to their variation. Initial maps of the vector components of the crustal magnetic field were derived by Langel from the Magsat data. These are shown in Figures 8a, 8b, and 8c for the Z component (vertical), the X component (north), and the Y component (east), respectively.

Detailed interpretations by Coles of Magsat data at high northern latitudes have shown convincing comparisons between the magnetic anomalies and large geological features in Canada. Crustal magnetic anomalies are being studied by Frey, who is interested in their correlation with global geological features, and in matching anomalies across continental boundaries. Syntheses of satellite gravity, magnetic, and imaging data, together with ground-based geophysical and geological data, are being used by Qureshy to study the structure of the Indian subcontinent and by Lavin and Alexander to study crustal structure in the eastern United States.

VI. ADVANCED STUDIES AND MISSIONS

Activities in this area are concentrated in three areas: methods of improvement of gravity and magnetic field measurements, development of capability for making rapid geodetic surveys of local deformation, and precise time transfer over intercontinental distances.

A. GRAVITY AND MAGNETIC FIELD MEASUREMENTS

The major effort has been design studies for the Geopotential Research Mission (GRM). The mission objectives are to produce global magnetic field models with an accuracy of 2nT in magnetic field magnitude (5nT in each component) and gravity field models with an accuracy of about 1 mgal; the horizontal resolution will be about 100 km for both types of measurement. The gravity field from GRM will provide nearly an order of magnitude improvement over current models for wavelengths from 100 to 1500 km. The magnetic field model will be an improvement of a factor of 4 over that produced by Magsat, and the second vector survey will be used to study secular variation of the geomagnetic field.

The GRM mission (Figure 9) will use measurement of relative acceleration between two spacecraft in 160 km orbit, 300 km apart, to determine the gravity field and Magsat instrumentation to make the magnetic measurements. Drag compensation will be done by sensing the position of a small proof mass in a cavity in each spacecraft and activating thrusters to maintain the mass in the center of the cavity. The relative velocity of the spacecraft must be measured to the order of one micron/second; in laboratory bread-board systems the range-rate system noise performance was found to be about 0.3 micron/second for four-second averaging times. Detailed simulations have been performed on the guidance and control systems.

Development of a cryogenic gravity gradiometer, which is a candidate for a post-GRM gravity field mapping mission, is continuing. The instrument appears to have the potential for improvement in resolution by a factor of 2 and in accuracy by a factor of 10 beyond that achievable by GRM. The instrument is an accelerometer consisting of a superconducting proof mass confined to move along a single axis, and a superconducting sensing coil located near the proof mass surface and connected to a SQUID. By differencing the outputs of the accelerometer pairs it is possible to measure the inline and cross components of the gravity tensor simultaneously. The expected sensitivity is better than $0.001 \text{ Eötvös/Hz}^{1/2}$. A single-axis laboratory prototype unit has been constructed and is being tested (Figure 10).

B. RAPID SURVEYS FOR LOCAL DEFORMATION

An Airborne Laser Ranging System (ALRS) is being studied, in which a laser mounted in an aircraft would be used to range to a grid of cube corner reflectors on the ground. Six-legged range measurements are made. Simulations have been made for a region 14 by 112 km, with reflector grid spacing of 7 km. With aircraft altitudes of 3.9 and 6.0 km, and assuming that meteorological information is available with an accuracy of 1 millibar, the distance between points 100 km apart could be determined in one day with a standard error of about 1.5 cm.

Another method for local surveying uses radio signals from the Global Positioning System satellites. NASA is supporting development of the SERIES system (Satellite Emission Range Inferred Earth Surveying). A pair of prototype stations are being constructed and will be tested in 1982 over baselines of 150m and 22km. Three-dimensional baseline accuracies of 0.5 to 3 cm over distances of 2 to 200 km are expected, with about ten minutes of on-site data acquisition time.

C. TIME TRANSFER

An experiment on the ESA SIRIO-2, Laser Synchronization from Stationary Orbit (LASSO), mission will use ground-based lasers which fire pulses at predicted times toward the geosynchronous SIRIO-2 spacecraft. Measurement of the two-way travel times will be used to establish the relative difference in time at the ground stations. A Shuttle time and frequency transfer experiment is also under study, in which the Shuttle would carry a hydrogen maser clock; transfer would be accomplished via a three-way microwave doppler system, and the clock could be interrogated by laser pulses from ground stations. Such a system would provide time transfer at the subnano-second level and frequency synchronization to one part in 10^{14} per day.

TABLE 1

Geodynamics Program Funding FY 1980-1983

(in millions)

| | <u>FY80</u> | <u>FY81</u> | <u>FY82</u> | <u>FY83*</u> |
|------------------------------------|-------------|-------------|-------------|--------------|
| Crustal Dynamics Project | \$9.6 | \$11.6 | \$14.0 | \$16.5 |
| Laser Network Operations | 10.8 | 10.9 | 6.5 | 7.0 |
| Research and Technique Development | 3.0 | 3.2 | 2.2 | 2.7 |
| Magsat Mission | 1.6 | 0.5 | 0.3 | 0.1 |
| GRM Studies | 0.3 | 0.9 | 0.7 | 0.5 |
| Total | 25.3 | 27.1 | 23.7 | 26.6 |

*Planned

APPENDIX 1

CRUSTAL DYNAMICS PROJECT INVESTIGATORS AND INVESTIGATIONS

Aardoom, L. (Delft University of Technology, Delft, The Netherlands): Development of SLR Techniques and their Application for Measuring Crustal Motion in Europe.

Agnew, D. C. (Scripps Institute of Oceanography, La Jolla, California): Application of Statistical Time Series Analysis Methods to the Study of Irregularities in Regional Crustal Deformation.

Anderson, A. J. (University of Uppsala, Sweden): Crustal Movements in Scandinavia using VLBI.

Ashkenazi, V. (University of Nottingham, England): Simultaneous Adjustment of Spatial and Terrestrial Geodetic Data.

Barlier, F. (CERGA/GRGS, Toulouse, France): SLR Techniques for Crustal Dynamics.

Bender, P. L. (National Bureau of Standards, University of Colorado, Boulder, Colorado): Analyzing the Accuracy of Reliability of Lageos-determined Baselines.

Bird, G. P. (University of California, Los Angeles, California): Testing Models of Crustal Flow and Fault Slip in California.

Boucher, C. (GRGS/IGN, Toulouse, France): VLBI Techniques for Crustal Dynamics.

Calame, O. (CERGA/GRGS, Grasse, France): Study of Earth-Moon System by Lunar Laser Data Analysis.

Calderon R., Gustavo (Instituto Oceanografico, Mexico): Geodetic Studies of the Gulf of California Region.

Clark, T. A. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Development of Observatory VLBI Techniques to Measure Contemporary Tectonic Plate Motion.

Dewey, J. F. (State University of New York, Albany, New York): Tectonic Studies of the Turkish East Anatolian Convergent Zone and Surrounding Areas by Field Studies, Landsat Imagery, and SLR and VLBI Data.

Fanselow, J. L. (Jet Propulsion Laboratory, Pasadena, California): Determination of Accurate Baselines and Empirical Strain Models from Mobile VLBI Data in the Western U.S.

Hager, B. H. (California Institute of Technology, Pasadena, California): Stress in the Lithosphere and the Driving Mechanisms for Plate Motions.

Jackson, D. D. (University of California, Los Angeles, California): Horizontal Tectonic Displacements in Southern California.

Johnson, T. (Lamont-Doherty Geological Observatory, Palisades, New York): Determination of Internal Deformation in Alaska and Pacific-North American Relative Plate Motion.

Johnston, K. J. (Naval Research Laboratory, Washington, DC): Measurement of Baselines to High Precision Using VLBI.

Jordan, T. H. (Scripps Institution of Oceanography, La Jolla, California): Predictions of the Motion of Project Sites, Comparisons with Observed Motions, and Development of New Numerical Models of Plate Motion.

Kahle, H.-G. (Institut für Geodesie and Photogrammetrie, Zürich, Switzerland): Geodynamic Processes in the Alpine Region.

Kausel, E. (Universidad de Chile, Santiago, Chile): Relative Motion of the Nazca and South America Plates, and Crustal Deformation in the Andes.

Kolenkiewicz, R. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Determination of Baselines Between SLR Sites in the Western U.S. from Lageos and BE-C Data.

Lago, B. (CNES/GRGS, Toulouse, France): Geophysical Interpretation of Spatial Geodetic Data.

Lambert, A. (Dept. of Energy, Mines and Resources, Ottawa, Canada): North American Plate Deformation in Canada.

Lerch, F. J. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Gravity Model Improvement from Lageos Data.

Lopez Arroyo, A. (Instituto Geografico Nacional, Madrid, Spain): Application of Geophysical, Geodetic, and Space Techniques to the Study of Crustal Dynamics and Seismicity in the Western Mediterranean.

Lyzenga, G. A. (Jet Propulsion Laboratory, Pasadena, California): Finite Element Modeling of Regional Strain and Crustal Deformation in California.

Marsh, J. G. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Determining the Center of Mass Coordinates of the Global Laser Ranging Stations to an Accuracy of 5 cm.

McCarthy, D. D. (U.S. Naval Observatory, Washington, DC): Rapid Determination of PM/UT.

Minster, J.-B. (Systems, Science, and Software, La Jolla, California): Predictions of the Motion of Project Sites, Comparisons with Observed Motions, and Development of New Numerical Models of Plate Motion.

Morgan, W. J. (Princeton University, New Jersey): Polar Motion and Variations in Earth Rotation and their Correlation with Other Geophysical Phenomena; Plate Rigidity and Plate Motion.

Ness, G. (Oregon State University): Geodetic Studies of the Gulf of California Region.

O'Connell, R. J. (Harvard University, Cambridge, Massachusetts): Large-scale Deformation of the Lithosphere and Smaller-scale Regional Lithospheric Deformation in the Western U.S.; Excitation of the Polar Wobble by Seismic and Aseismic Events.

Oliver, J. E. (Cornell University, Ithaca, New York): Regional Deformation at Plate Boundaries in Southern California and Alaska; Internal Deformation of the North American Plate.

Rogers, A. E. E. (Haystack Observatory/NEROC, Westford, Massachusetts): Development of High Precision VLBI Techniques to Achieve a 3-sigma Accuracy in Baseline Length Determination of Less Than 1 cm.

Rosen, R. D. (Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts): Atmospheric Excitation of Changes in Earth Rotation and Polar Motion.

Rundle, J. B. (Sandia National Laboratory, Albuquerque, New Mexico): Regional Strain Accumulation Models in Southern California; Determination of Material Properties of the Lithosphere at Depth.

Ryan, J. W. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Intercomparison of Baselines Determined by both SLR and VLBI Techniques.

Scholz, C. H. (Lamont-Doherty Geological Observatory, Palisades, New York): Tectonic Studies in California; Interpretation of Crustal Motions Along the San Andreas Fault.

Shaffer, D. B. (Phoenix Corporation, McLean, Virginia): Improving the VLBI Reference Frame Through Development of an Improved Catalog of Compact Radio Sources.

Shapiro, I. I. (Massachusetts Institute of Technology, Cambridge, Massachusetts): VLBI Techniques for Reliable Determination of the Motion and Deformation of North American and Eurasian Plates.

Shapiro, I. I. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Determination of UT, Polar Motion, Nutation, GM Earth, and Solid Earth Tides Through Analysis of Lunar Laser Data.

Shelus, P. J. (University of Texas, Austin, Texas): Earth Rotation and Polar Motion Parameters from Lunar Laser and Lageos Data.

Smith, D. E. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Determination of the Positions and Relative Motions of All the Fixed and Mobile Laser Ranging Stations.

Solomon, S. C. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Studies of Plate Driving Forces; Mechanical Properties of the Lithosphere and Asthenosphere.

Stein, S. (Northwestern University, Evanston, Illinois): Studies of Regional Deformation in the Great Basin Area of the Western U.S., and Within Oceanic Plates.

Stolz, A. (University of New South Wales, Sydney, NSW, Australia): SLR Measurements in Australia.

Stolz, A. (University of New South Wales, Sydney, NSW, Australia): VLBI Measurements in Australia.

Tapley, B. D. (University of Texas, Austin, Texas): Technique Development for the Analysis of SLR Data to Obtain TLRs Coordinates, SLR Network Coordinates, Global Baselines, Polar Motion, Length of Day, and UT1; Interpretation in Terms of Geophysical Signal and Characteristics of Error Sources Associated with SLR Techniques.

Torge, W. (Universität Hannover, West Germany): High-precision Gravity Network in the Aegean Region.

Turcotte, D. L. (Cornell University, Ithaca, New York): Models of Strain Accumulation and Stress Release Adjacent to the San Andreas Fault.

Walcott, R. I. (Dept. of Scientific and Industrial Research, Wellington, New Zealand): Crustal Deformation Measurements in New Zealand.

Whitcomb, J. H. (CIRES, University of Colorado, Boulder, Colorado): Correlation of Project-acquired Data in the Western U.S. with Other Geophysical Parameters (Gravity, Seismic, Radon).

Williams, J. G. (Jet Propulsion Laboratory, Pasadena, California): Determination of GM Earth, Coordinates of Lunar Laser Stations and the Phase of the M2 Tide from LLR Data; Modeling the Earth-Moon System at the 3-5 cm Level.

Wilson, P. (Institut für Angewandte Geodäsie, Frankfurt, West Germany): Development of SLR and VLBI Techniques to Measure Crustal Motion in the Eastern Mediterranean.

Wyss, M. (CIRES, University of Colorado, Boulder, Colorado): Tectonics of the Aegean and Surrounding Areas.

Ye Shu-Hua (Shanghai Observatory, Shanghai, People's Republic of China): Development of Space Geodetic Techniques in China.

Yoder, C. F. (Jet Propulsion Laboratory, Pasadena, California): Geophysical Sources of Variable Earth Rotation.

APPENDIX 2

Investigations Selected In Response to the Applications Notice, 1981

Berger, J. (University of California, La Jolla, California): Precision Measurement of Benchmark and Monument Displacements for Use in Crustal Dynamics Studies.

Cohen, S. C. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Models of Coseismic and Postseismic Deformation.

Counselman, C. C. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Very Long Baseline Interferometry with GPS Satellites.

Crough, S. T. (Purdue University, West Lafayette, Indiana): Geoid Height and the Thickness of the Lithosphere.

Daly, S. (Jet Propulsion Laboratory, Pasadena, California): Mantle Convection with Variable Properties.

Dickman, S. R. (State University of New York, Binghamton, New York); Further Investigation into Effects of the Oceans on Polar Motion.

Felsentreger, T. L. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Estimation of Solid Earth/Ocean Tidal Parameters from Satellite Tracking Data.

Frey, H. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Satellite Geopotential Anomalies: Global Distribution and Relation to Surface Data.

Frey, H. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Age of Satellite-Observed Magnetic and Gravity Anomalies Using Paleo-Reconstructions.

Jones, G. M. (Texas A&M University, Bryan, Texas): Altimetry Data and the Deep Structure of Subduction Zones.

Kaula, W. M. (University of California, Los Angeles, California): Earth Dynamics Analyses.

Lowman, P. D. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Late Cenozoic Tectonics of the Basin and Range Province and the San Andreas Fault System.

Marsh, B. D. (Johns Hopkins University, Baltimore, Maryland): Delineation and Interpretation of the Earth's Gravity Field.

McAdoo, D. C. (NASA Goddard Space Flight Center, Greenbelt, Maryland): Dynamic Processes of Convergent Plate Margins.

Molnar, P. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Study of Seismic Wave Velocity Structure in the Downgoing Slab and the Olivine-Spinel Phase Change.

Molnar, P. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Seismicity and Active Tectonics of the Andes and the Origin of the Altiplano.

Mueller, I. I. (Ohio State University, Columbus, Ohio): Inter-comparison of Different Space Geodetic Measurement and Computational Techniques for the Establishment of a Terrestrial Reference Coordinate System for Earth Dynamics.

Nur, A. (Stanford University, Stanford, California): Models for Rupture Mechanics of Plate Boundaries and Crustal Deformation.

Rapp, R. H. (Ohio State University, Columbus, Ohio): Improvement of the Earth's Gravity Field from Terrestrial and Satellite Data.

Roufousse, M. C. (Smithsonian Astrophysical Observatory, Cambridge, Massachusetts): Global Study of the Time Evolution of the Lithosphere Using GEOS-3 and Seasat Radar Altimeter.

Roman, N. G. (ORI, Inc., Greenbelt, Maryland): Critical Review of the Use of VLBI for Geodesy.

Schubert, G. (University of California, Los Angeles, California): Thermal Isostasy in the World's Oceans.

Solomon, S. C. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Application of Laser Ranging and VLBI Data to a Study of Plate Tectonic Driving Forces.

Toksöz, M. N. (Massachusetts Institute of Technology, Cambridge, Massachusetts): Geophysical Study of the Structure and Processes of Continental Convergence Zones of the Alpine-Himalayan Belt.

Wu, F. T. (State University of New York, Binghamton, New York); Crustal Dynamics Studies in The People's Republic of China.

Whitcomb, J. H. (CIRES, University of Colorado, Boulder, Colorado): Modeling of Tectonophysical Distortion from Measurements of Long Baseline Geodetic Data and Other Geophysical Parameters.

APPENDIX 3Glossary of Acronyms and Abbreviations

| | |
|----------|---|
| ALRS | Airborne Laser Ranging System |
| AN | Applications Notice |
| AO | Announcement of Opportunity |
| BIH | Bureau International de l'Heure |
| CNES | Centre National d'Etudes Spatiales (France) |
| CNR | Consiglio Nazionale delle Recerche (Italy) |
| CDP | Crustal Dynamics Project |
| CSTG | Commission on International Coordination of Space Techniques for Geodesy and Geodynamics |
| DMA | Defense Mapping Agency |
| DOC | Department of Commerce |
| DOD | Department of Defense |
| DSN | Deep Space Network |
| DSS | Deep Space Station |
| ESA | European Space Agency |
| FY | Fiscal Year |
| GEM | Goddard Earth Model |
| GEODYN | Goddard Computer Program for Geodynamics and Orbital Computations |
| GEOS | Geodynamic Experimental Ocean Satellite |
| GPS | Global Positioning System |
| GRM | Geopotential Research Mission |
| GSFC | Goddard Space Flight Center |
| GUWG | Gravsat User Working Group |
| HO | Haystack Observatory |
| HRAS | Harvard Radio Astronomy Station |
| IAG | International Association of Geodesy |
| IAGA | International Association of Geomagnetism and Aeronomy |
| IAU | International Astronomical Union |
| ICCG | Interagency Coordinating Committee for Geodynamics |
| ICSU | International Council of Scientific Unions |
| ICL | Inter-Union Commission on the Lithosphere |
| IGRF | International Geomagnetic Reference Field |
| ILP | International Lithosphere Program |
| IUGG | International Union of Geodesy and Geophysics |
| IUGS | International Union of Geological Sciences |
| JHD | Japanese Hydrographic Department |
| JPL | Jet Propulsion Laboratory |
| Lageos | Laser Geodynamics Satellite |
| LASSO | Laser Synchronization from Stationary Orbit |
| LLR | Lunar Laser Ranging |
| LURE | Lunar Ranging Experiment |
| Magsat | Magnetic Field Satellite |
| Mark-III | Advanced VLBI Data System |
| MERIT | Monitoring Earth Rotation and Inter- comparison of Techniques |
| MLRS | McDonald Laser Ranging Station |

| | |
|---------|--|
| Moblas | Mobile Laser System |
| MSFC | Marshall Space Flight Center |
| MV | Mobile VLBI |
| NAS/NRC | National Academy of Sciences - National Research Council |
| NASA | National Aeronautics and Space Administration |
| Natmap | Division of National Mapping (Australia) |
| NBS | National Bureau of Standards |
| NCMM | National Crustal Motion Network |
| NGS | National Geodetic Survey |
| NEROC | Northeastern Radio Observatory Corporation |
| NGSP | National Geodetic Satellite Program |
| NLRS | Natmap Laser Ranging Station |
| NOAA | National Oceanic and Atmospheric Administration |
| NRAO | National Radio Astronomy Observatory |
| NSF | National Science Foundation |
| NSSDC | National Space Science Data Center |
| NSWC | Naval Surface Weapons Center |
| OSSA | Office of Space Science and Applications |
| OVRO | Owens Valley Radio Observatory |
| PM | Polar Motion |
| Polaris | Polar Motion Analysis by Radio Interferometric Systems |
| PRB | Program Review Board (Geodynamics) |
| RRL | Radio Research Laboratory (Japan) |
| RTD | Research and Technology Development |
| RTOP | Research and Technology Objectives and Plan |
| SAFE | San Andreas Fault Experiment |
| SAO | Smithsonian Astrophysical Observatory |
| SERIES | Satellite Emission Range Inferred Earth Surveying |
| SLR | Satellite Laser Ranging |
| Stalas | Stationary Laser System |
| STDN | Space Tracking and Data Network |
| TLRS | Transportable Laser Ranging Station |
| USGS | United States Geological Survey |
| USNO | United States Naval Observatory |
| VLA | Very Large Array |
| VLBI | Very Long Baseline Interferometry |
| UT | Universal Time |
| WVR | Water Vapor Radiometer |

APPENDIX 4

PUBLICATIONS ON RESEARCH SUPPORTED BY THE NASA GEODYNAMICS PROGRAM

Araki, T., T. Iyemori, S. Tsunomura, T. Kamei, and H. Maeda, Detection of an Ionospheric Current for the Preliminary Impulse of the Geomagnetic Sudden Commencement. Geophys. Res. Lett. 9, 4, 341-344, 1982.

Archinal, B., and I. I. Mueller, A Comparison of Geodetic Doppler Satellite Receivers. Proc. Third International Geodetic Symposium on Satellite Doppler Positioning, 1982.

Aydin, A., and A. Nur, Evolution of Pull-apart Basins and their Scale Independence. Tectonics, in press, 1982.

Bender, P. L., Establishment of Terrestrial Reference Frames by New Observational Techniques. In Reference Coordinate Systems for Earth Dynamics, ed. E. M. Gaposchkin and B. Kolaczek, D. Reidel, Dordrecht, 23-36, 1981.

Benton, E. R., and M. C. Coulter, Frozen-Flux Upper Limits to the Magnitudes of Geomagnetic Gauss Coefficients, Based on Magsat Observations. Geophys. Res. Lett. 9, 4, 262-264, 1982.

Benton, E. R., R. H. Estes, R. A. Langel, and L. A. Muth, Sensitivity of Selected Geomagnetic Properties to Truncation Level of Spherical Harmonic Expansions. Geophys. Res. Lett. 9, 4, 254-257, 1982.

Bergman, E. A., and S. C. Solomon, Intraplate Stress, in Encyclopedia of Structural Geology and Plate Tectonics, ed. C. K. Seyfert, Hutchinson Ross, Stroudsburg, Penna., 1982.

Bergman, E. A., and S. C. Solomon, Oceanic Intraplate Earthquakes and Stresses Near Large Bathymetric Features. EOS Trans. Amer. Geophys. Union 63, in press, 1982.

Brammer, R. F., R. V. Sailor, and A. R. Lazarewicz, Magsat Investigation of Lithospheric Magnetic Anomalies in the Eastern Indian Ocean. IAGA Bull. No. 45, 111, 1981.

Brown, R. D., W. D. Kahn, D. C. McAdoo, and W. E. Himwich, Roughness of the Marine Geoid from Seasat Altimetry. Submitted for publication, 1982.

Carle, H. M., and C. G. A. Harrison, A Problem in Representing the Core Magnetic Field of the Earth Using Spherical Harmonics. Geophys. Res. Lett. 9, 4, 265-268, 1982.

Chen, C. H., W. P. Chen, and P. Molnar, The Uppermost Mantle P-wave Velocities Beneath Turkey and Iran. Geophys. Res. Lett. 7, 77-80, 1980.

Chen, W. P., and P. Molnar, Constraints on the Seismic Wave Velocity Structure Beneath the Tibetan Plateau and their Tectonic Implications. J. Geophys. Res. 86, 5937-5962, 1981.

Chen, W. P., and P. Molnar, Constraints on the Seismic Wave Velocity Structure Beneath the Tibetan Plateau, in Proceedings of the Symposium on the Tibetan Plateau (in press), Beijing, 1982.

Cohen, S. C., Postseismic Rebound Due to Creep of the Lower Lithosphere and Asthenosphere. Geophys. Res. Lett. 8, 493-496, 1981.

Cohen, S. C., Relationships Among the Slopes of Lines Derived from Various Data Analysis Techniques and the Associated Correlation Coefficient. Geophysics 46, 1606, 1981.

Cohen, S. C., A multilayer Model of Time-dependent Deformation Following an Earthquake on a Strike-slip Fault. J. Geophys. Res., in press, 1982.

Cohen, S. C., and T. Peck, Reports on Crustal Movements and Deformations. NASA TM-83872, Goddard Space Flight Center, Greenbelt, Maryland, 1981.

Coles, R. L., G. V. Haines, G. Jansen van Beek, A. Nandi, and J. K. Walker, Magnetic Anomaly Maps From 40° N to 83° N Derived from Magsat Satellite Data. Geophys. Res. Lett. 9, 4, 281-284, 1982.

Colombo, O. L., Global Geopotential Modeling from Satellite-to-Satellite Tracking. Ohio State Univ. Dept. Geodetic Science Rept. 317, 1981.

Counselman, C. C., and S. A. Gourevitch, Miniature Interferometer Terminals for Earth Surveying: Ambiguity and Multipath with Global Positioning System. IEEE Trans. Geoscience and Remote Sensing GE-19, 244-252, 1981.

Counselman, C. C., and 8 others, Accuracy of Baseline Determinations by Mites Assessed by Comparison with Tape, Theodolite, and Geodimeter Measurements. EOS 62, 17, 260, 1981.

Counselman, C. C., and ten others, Accuracy of Relative Positioning by Interferometry with GPS: Double-blind Test Results. Proc. Third Internat. Symposium on Satellite Doppler Positioning, 1982.

Dalmayrac, B., and P. Molnar, Parallel Thrust and Normal Faulting in Peru and Constraints on the State of Stress. Earth and Planetary Science Lett. 55, 473-481, 1981.

Dickey, J. O., H. F. Fliegel, and J. G. Williams, Universal Time, UT1, from Lunar Laser Ranging Observations. BIH Annual Report, 1981.

Dickey, J. O., H. F. Fliegel, and J. G. Williams, Comparison of Polar Motion Results Using Lunar Laser Ranging, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Dickey, J. O., J. G. Williams, and C. F. Yoder, Results from Lunar Laser Ranging Data Analysis, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Dickman, Steven R., The Rotation of the Ocean-Solid Earth System. J. Geophys. Res., in press, 1982.

Ekkebus, E. J., Problems in Attaining Accurate State Estimates from an Extended Kalman Filter, Processing Laser Range-only Observations from a Single Tracking Station. Technical Thesis, Delft University of Technology, Dept. Aerospace Engineering, 1981.

Fliegel, H. F., J. O. Dickey, and J. G. Williams, Intercomparison of Lunar Laser and Traditional Determinations of Earth Rotation, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Frey, H., Magsat Scalar Anomalies and Major Tectonic Boundaries in Asia. Geophys. Res. Lett. 9, 4, 299-302, 1982.

Frey, H., Magsat Scalar Anomaly Distribution: The Global Perspective. Geophys. Res. Lett. 9, 4, 277-280, 1982.

Galliher, S. C., and M. A. Mayhew, On the Possibility of Detecting Large-Scale Crustal Remanent Magnetization With Magsat Vector Magnetic Anomaly Data. Geophys. Res. Lett. 9, 4, 325-328, 1982.

Hajela, D. P., A Simulation Study to Test the Prediction of $1^\circ \times 1^\circ$ Mean Gravity Anomalies Using Least Squares Collocation from the Gravsat Mission. Ohio State Univ. Dept. Geodetic Science Rept. 316, 1981.

Hastings, D. A., Preliminary Correlations of Magsat Anomalies with Tectonic Features in Africa. Geophys. Res. Lett. 9, 4, 303-306, 1982.

Hermance, J. F., Model Simulations of Possible Electromagnetic Induction Effects at Magsat Activities. Geophys. Res. Lett. 9, 4, 373-376, 1982.

Herring, T. A., and 16 others, Determination of Tidal Parameters from VLBI Observations, in Proceedings of the Ninth International Symposium on Earth Tides, New York, 1981.

Herring, T. A., and 16 others, Geodesy by Radio Interferometry: Intercontinental Distance Determinations with Subdecimeter Precision. J. Geophys. Res. 86 B3, 1647-1651, 1981.

Herring, T. A., I. I. Shapiro, N. H. Bartel, B. E. Corey, A. E. E. Rogers, Geodesy by Radio Interferometry: Ionospheric Effects. EOS 62, 17, 620, 1981.

Hinze, W. J., R. R. B. Von Frese, M. B. Longacre, L. W. Braile, E. G. Lidiak, and G. R. Keller, Regional Magnetic and Gravity Anomalies of South America. Geophys. Res. Lett. 9, 4, 314-317, 1982.

Houseman, G. A., D. P. McKenzie, and P. Molnar, Convective Instability of a Thickened Boundary Layer and its Relevance for the Thermal Evolution of Continental Convergent Belts. J. Geophys. Res. 86, 6115-6132, 1981.

Hsui, A. T., B. D. Marsh, and M. N. Toksöz, On Melting of the Subducted Oceanic Crust: Effect on Subduction Induced Mantle Flow. Tectonophysics, in press, 1982.

Hsui, A. T., and M. N. Toksöz, The Evolution of Thermal Structures Beneath a Subduction Zone. Tectonophysics 60, 43-60, 1979.

Hsui, A. T., and M. N. Toksöz, Back Arc Spreading: Trench Migration, Continental Pull or Induced Convection. Tectonophysics 74, 89-98, 1981.

Hughes, T. J., D. D. Wallis, J. R. Burrows, and M. D. Wilson, Model Predictions of Magnetic Perturbations Observed by Magsat in Dawn-Dusk Orbit. Geophys. Res. Lett. 9, 4, 357-360, 1982.

Iijima, T., N. Fukushima, and R. Fujii, Transverse and Parallel Geomagnetic Perturbations Over the Polar Regions Observed by Magsat. Geophys. Res. Lett. 9, 4, 369-372, 1982.

Jones, G. M., A Technique for Computing Geoid Height Anomalies Over Two-dimensional Earth Models. Geophys. J. Roy. Astron. Soc., in press, 1982.

Jones, G. M., Isostatic Geoid Anomalies Over Trenches and Island Arcs. Geophys. J. Roy. Astron. Soc., submitted 1982.

Kaula, W. M., Problems in Understanding Vertical Movements and Earth Rheology. Earth Rheology, Isostasy, and Eustasy, N. A. Mörner, ed., John Wiley & Sons, Chichester, 577-588, 1980.

Kaula, W. M., Material Properties for Mantle Convection Consistent with Observed Surface Fields. J. Geophys. Res. 85, 7031-7044, 1980.

Kaula, W. M., Geodynamics from Satellites. Advan. Astronaut. Sci. 41, 627-631, 1980.

Kaula, W. M., The Next Development in Satellite Determination of the Earth's Gravity Field. Proc. USA-Hungarian Workshop on Dynamics, B. J. Balasz, Ed., Eötvös Univ., Budapest, 1982.

Kaula, W. M., Minimal Upper Mantle Temperature Variations Consistent with Observed Heat Flow and Plate Velocities. J. Geophys. Res., submitted 1982.

Kaula, W. M., Inference of Variations in the Gravity Field from Satellite-to-Satellite Range-rate. J. Geophys. Res., submitted 1982.

Klosko, S. M., J. G. Marsh, F. J. Lerch, and R. G. Williamson, Gravity Model Improvement for Seasat. J. Geophys. Res., in press, 1982.

Klumpar, D. M., and D. M. Greer, A Technique for Modeling the Magnetic Perturbations Produced by Field-Aligned Current Systems. Geophys. Res. Lett. 9, 4, 361-364, 1982.

Langel, R. A., The Magnetic Earth as Seen from Magsat, Initial Results. Geophys. Res. Lett. 9, 4, 239-242, 1982.

Langel, R. A., R. H. Estes, and G. D. Mead, Some New Methods in Geomagnetic Field Modeling Applied to the 1960-1980 Epoch. NASA Tech. Mem. 83868, 1981.

Langel, R. A., R. H. Estes, and G. D. Mead, Some New Methods in Geomagnetic Field Modeling Applied to the 1960-1980 Epoch. J. Geomag. Geoelect., in press, 1982.

Langel, R. A., and R. H. Estes, A Geomagnetic Field Spectrum. Geophys. Res. Lett., 1982.

Langel, R. A., G. Ousley, J. Berbert, J. Murphy, and M. Settle, The Magsat Mission. Geophys. Res. Lett. 9, 4, 243-245, 1982.

Langel, R. A., J. D. Phillips, and R. J. Horner, Initial Scalar Magnetic Anomaly Map from Magsat, Geophys. Res. Lett. 9, 4, 269-272, 1982.

Langel, R. A., C. C. Schnetzler, J. D. Phillips, and R. J. Horner, Initial Vector Magnetic Anomaly Map from Magsat, Geophys. Res. Lett. 9, 4, 273-276, 1982.

Langel, R. A., and L. Thorning, Satellite Magnetic Field Over the Nares Strait Region, in Nares Strait: A Central Conflict in Plate Tectonics Studies of the Arctic, ed. P. R. Doves and J. W. Ken: Medd. Grønland Geosci., 1982.

Langel, R. A., and L. Thorning, A Magnetic Anomaly Map of Greenland. Geophys. J. Roy. Astron. Soc., in press, 1982.

Langley, R. B., R. W. King, and I. I. Shapiro, Earth Rotation from Lunar Laser Ranging. J. Geophys. Res. 86, 11913-11918, 1981.

Langley, R. B., R. W. King, I. I. Shapiro, R. D. Rosen, and D. A. Salstein, Atmospheric Angular Momentum and Length of Day: A Common Fluctuation with Period Near 50 Days. Nature 294, 730-732, 1981.

Langley, R. B., R. W. King, P. J. Morgan, and I. I. Shapiro, Rotation of the Earth from Lunar Laser Ranging, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Latimer, J. H., D. M. Hills, S. D. Vrtilek, A. Chaiken, D. A. Arnold, and M. R. Pearlman, An Evaluation and Upgrading of the SAO Prediction Technique. Proc. Fourth International Workshop on Laser Ranging Instrumentation, 1981.

Latimer, J. H., J. M. Thorp, D. R. Hanlon, and G. E. Gullahorn, A Review of Network Data Handling Procedures. Proc. Fourth International Workshop on Laser Ranging Instrumentation, 1981.

Liu, C. S., D. T. Sandwell, and J. R. Curray, The Negative Gravity Field Over the 85°E Ridge. J. Geophys. Res., in press, 1982.

Longacre, M. B., W. J. Hinze, and R. R. B. von Frese, A Satellite Magnetic Model of Northeastern South American Aulacogens. Geophys. Res. Lett. 9, 4, 318-321, 1982.

Lowman, P. D., A Global Tectonic Activity Map with Orbital Photographic Supplement. NASA Tech. Mem. 82073, Greenbelt, Maryland, 1981.

Lowman, P. D., A Global Tectonic Activity Map. Bull. Internat. Assoc. Engineering Geology 23, 37-49, 1981.

Lowman, P. D., and H. V. Frey, A Geophysical Atlas for Interpretation of Satellite-Derived Data. NASA Tech. Mem. 79722, Greenbelt, Maryland, 1979.

Lowman, P. D., Crustal Evolution in Silicate Planets: Implications for the Origin of Continents. J. Geol. 84, 1-26, 1976.

Maeda, H., T. Iyemori, T. Araki, and T. Kamei, New Evidence of a Meridional Current System in the Equatorial Ionosphere. Geophys. Res. Lett. 9, 4, 337-340, 1982.

Marsh, J. G., R. E. Cheney, T. V. Martin, and J. J. McCarthy, Computation of a Precise Mean Sea Surface in the Eastern North Pacific Using SEASAT Altimetry. EOS 63, 9, 178-179, 1982.

Marsh, J. G., B. D. Marsh, R. G. Williamson, and W. T. Wells, The Gravity Field in the Central Pacific from Satellite-to-Satellite Tracking. J. Geophys. Res. 86, 3979-3997, 1981.

Marsh, J. G., and R. G. Williamson, Starlette Laser Data Analyses for Precision Orbit Determination. In press, 1982.

Mayhew, M. A., and S. C. Galliher, An Equivalent Layer Magnetization Model for the United States Derived from Magsat Data. Geophys. Res. Lett. 9, 4, 311-313, 1982.

McAdoo, D. C., On the Compensation of Geoid Anomalies Due to Subducting Slabs. NASA TM-82156, Goddard Space Flight Center, Greenbelt, Maryland, 1981.

McCarthy, D. D., An Intercomparison of Connected Element Interferometer and Lunar Laser Earth Rotation Parameters, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Mignard, F., Action de l'atmosphere Neutre et Ionisee Sur le Mouvement d'un Satellite - Application a Lageos. Ann. Geophys. 37, 247-252, 1981.

Molnar, P., and W. P. Chen, Constraints of the Amount of North-South Shortening in Tibet During the Cenozoic, in Proceedings of the Symposium on the Tibetan Plateau, in press, Beijing, 1982.

Molnar, P., and D. Gray, Subduction of Continental Lithosphere: Some Constraints and Uncertainties. Geology 7, 58-62, 1979.

Molnar, P., and P. Tapponnier, A Possible Dependence of Tectonic Strength on the Age of the Crust in Asia. Earth Planet. Sci. Lett. 52, 107-114, 1981.

Morgan, P. J., and R. W. King, Determination of Coordinates for the Orroral Lunar Laser Ranging Station, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Mueller, I. I., Tecnicas Geodesicas Tridimensionales. J. Asociacion Salvadorena de Ingenieros y Arquitectos No. 61, p. 40-51; No. 62, p. 31-39, 1980.

Mueller, I. I., Space Geodetic Techniques and Geodynamics. Proc. First International Symposium on Crustal Movements in Africa, 1981.

Mueller, I. I., and B. Archinal, Geodesy and the Global Positioning System. Proc. IAG Symposium on Geodetic Networks and Computations, 1981.

Mueller, I. I., B. S. Rajal, and Y. S. Zhu, Comparison of polar Motion Data from the 1980 Project Merit Short Campaign. Proceedings IAU Colloq. 63 on High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations (Reidel), 1981.

Mueller, I. I., S.-Y. Zhu, & Y. Bock, Reference Frame Requirements and the MERIT Campaign - Proposal for Extra Observations. Dept. Geodetic Science and Surveying Report 329, Ohio State University, 1982.

Newitt, L. R., E. Dawson, R. L. Coles, and A. Nandi, Magnetic Charts of Canada Derived from Magsat Data. Geophys. Res. Lett. 9, 4, 246-249, 1982.

Pearlman, M. R., N. Lanham, J. Wohn, and J. Thorp, Current Status and Upgrading of the SAO Laser Ranging Systems. Proc. Fourth International Workshop on Laser Ranging Instrumentation, 1981.

Pearlman, M. R., Some Current Issues in Satellite Laser Ranging. Proc. Fourth International Workshop on Laser Ranging Instrumentation, 1981.

Pearlman, M. R., N. Lanham, J. Thorp, and J. Wohn, SAO Calibration Techniques. Proc. Fourth International Workshop on Laser Ranging Instrumentation, 1981.

Rapp, R. H., Ellipsoidal Corrections for Geoid Undulation Computations Using Gravity Anomalies in a Cap. J. Geophys. Res. 86, 10843-10848, 1981.

Rapp, R. H., Degree Variance of the Earth's Potential, Topography and its Isostatic Compensation. Bull. Geodesique, in press, 1982.

Reilinger, R. E., and J. Adams, Geodetic Evidence for Active Landward Tilting of the Oregon and Washington Coastal Ranges. geophys. res. lett., 9, 4, 401-403, 1982.

Reilinger, R. E., and L. D. Brown, Neotectonic Deformation, Near Surface Movements and Systematic Errors in U.S. Releveling Measurements: Implications for Earthquake Prediction, in Earth Prediction - An International Review, 422-440, eds. D. W. Simpson and P. G. Richards, Maurice Ewing Series #4, Amer. Geophys. Union, Washington, 1981.

Resch, G. M., Water vapor - the Wet Blanket of Microwave Interferometry, in Atmospheric Water Vapor, eds. Deepak, Wilkerson, and Ruhnke, Academic Press, New York, 1980.

Ritzwoller, M. H., and C. R. Bentley, Magsat Magnetic Anomalies Over Antarctica and the Surrounding Oceans. Geophys. Res. Lett. 9, 4, 285-288, 1982.

Roecker, S. W., Velocity structure of the Pamir-Hindu Kush region: Possible Evidence of Subducted Crust. J. Geophys. Res. 87, 945-959, 1982.

Rowlands, D., The Adjustment of Seasat Altimeter Data on a Global Basis for Geoid and Sea Surface Height Determinations. Ohio State Univ. Dept. Geodetic Science Rept. 325, 1981.

Rubincam, D. P., Information Theory Lateral Density Distribution for Earth Inferred from Global Gravity Field. NASA Tech. Mem. 83825, Greenbelt, Maryland, 1981.

Sailor, R. V., A. R. Lazarewicz, and R. F. Brammer, Spatial Resolution and Repeatability of Magsat Crustal Anomaly Data Over the Indian Ocean. Geophys. Res. Lett. 9, 4, 289-292, 1982.

Sandwell, D. T., and G. Schubert, Geoid Height Versus Age for Symmetric Spreading Ridges. J. Geophys. Res. 85, 7235-7241, 1980.

Sandwell, D. T., and G. Schubert, Geoid Height-Age Relation from Seasat Altimeter Profiles Across the Mendocino Fracture Zone. J. Geophys. Res., in press, 1982.

Sandwell, D. T., and G. Schubert, Lithospheric Flexure at Fracture Zones. J. Geophys. Res., in press, 1982.

Sandwell, D. T., and K. A. Poehls, A Compensation Mechanism for the Central Pacific. J. Geophys. Res. 85, 3751-3758, 1980.

Schilt, F. S., and R. E. Reilinger, Evidence for Contemporary Vertical Fault Displacement from Precise Leveling Near the New Madrid Seismic Zone, Western Kentucky. Bull. Seism. Soc. Amer. 71, 1933-1942, 1981.

Schmitz, D., J. B. Frayser, and J. C. Cain, Application of Dipole Modeling to Magnetic Anomalies. Geophys. Res. Lett. 9, 4, 307-310, 1982.

Schneeberger, R., D. Pavlis, and I. I. Mueller, Use of Simultaneous Doppler-Derived Ranges in the Geometric Mode. Proc. Third International Geodetic Symposium on Satellite Doppler Positioning, 1982.

Scholz, C. H., Scaling Laws for Large Earthquakes: Consequences for Physical Models. Bull. Seism. Soc. Amer. 72, 1-14, 1982.

Shapiro, I. I., Geodesy by Radio Interferometry: A Critical Review, in IEEE Digest, 1981 International Geoscience and Remote Sharing Symposium (IGARSS '81), 1, 206-217, 1981.

Suarez, G., Earthquake Mechanisms and the Depth of Faulting in the Central Andes. Earthquake Notes 52, 67, 1981.

Suzuki, A., and N. Fukushima, Sunward or Anti-Sunward Electric Current in Space Below the Magsat Level. Geophys. Res. Lett. 9, 4, 345-348, 1982.

Taylor, P. T., A. F. Schanzle, T. L. Jones, R. A. Langel, and W. D. Kahn, Influence of Gravity Field Uncertainties on the Results from POGO and Magsat Geomagnetic Surveys, Geophys. Res. Lett. 12, 1246-1248, 1981.

Toksöz, M. N., W. R. Buck, and A. T. Hsui, Crustal Evolution and Thermal State of Tibet, in Proceedings of the Symposium on the Tibetan Plateau, in press, Beijing, 1982.

van Hulzen, J. J. P., Kalman Filter Satellite Orbit Determination Using Single-Station Laser Ranging Observations. Technical Thesis, Delft University of Technology, Dept. Aerospace Engineering, 1981.

Vermeer, M., Kalman Filter Orbit Determination for Geodetic Satellite Laser Ranging; a Theoretical Inquiry. Thesis, Delft University of Technology, Dept. Aerospace Engineering, 1981.

von Frese, R. R. B., W. J. Hinze, J. L. Sexton, and L. W. Braile, Verification of the Crustal Component in Satellite Magnetic Data. Geophys. Res. Lett. 9, 4, 293-295, 1982.

Voorhies, C. V., and E. R. Benton, Pole Strength of the Earth from Magsat and Magnetic Determination of the Core Radius. Geophys. Res. Lett. 9, 4, 258-261, 1982.

Wakker, K. F., B. A. C. Ambrosius, and J. J. P. van Hulzen, Kalman Filter Orbit Improvement from Kootwijk Laser Range Observations. Adv. Space Res. 1, 79-82, 1981.

Wakker, K. F., and B. A. C. Ambrosius, Kalman Filter Satellite Orbit Improvement Using Laser Range Measurements from a Single Tracking Station, in Advances in Theory and Technology of Applications of Nonlinear Filters and Kalman Filters (AGARD), in press, 1982.

Wakker, K. F., and B. A. C. Ambrosius, Accurate Orbit Determinations from Laser Ranging Observations of Lageos, Starlette, and Geos-3. ESA SP-160, p. 25-35, 1981.

Wakker, K. F., and B. A. C. Ambrosius, Some Results of Numerical Experiments on the Computation of the Kootwijk and Wettzell Satellite Laser Ranging Station Coordinates. Delft University of Technology, Dept. Aerospace Engineering Memorandum M-409, 1981.

Wakker, K. F., B. A. C. Ambrosius, and T. van der Ploeg, Preliminary Results of Seasat Orbit Determinations from Laser Range and European Doppler Observations. Delft University of Technology, Dept. Aerospace Engineering Memorandum M-411, 1981.

Wallis, D. D., J. R. Burrows, T. J. Hughes, and M. D. Wilson, Eccentric Dipole Coordinates for Magsat Data Presentation and Analysis of External Current Effects. Geophys. Res. Lett. 9, 4, 353- 356, 1982.

Wasilewski, P., and D. M. Fountain, The Ivrea Zone as a Model for the Distribution of Magnetization in the Continental Crust. Geophys. Res. Lett. 9, 4, 333-336, 1982.

Wasilewski, P., and Mayhew, M. A., Crustal Xenolith Magnetic Properties and Long Wavelength Anomaly Source Requirements. Geophys. Res. Lett. 9, 4, 329-332, 1982.

Williams, J. G., Lunar and Planetary Ephemerides: Accuracy, Inertial Frames, and Zero Points. Proc. Fourth Internat. Workshop on Laser Ranging Instrumentation, 1981.

Williams, J. G., and W. G. Melbourne, Comments on the Effects of Adopting New Precessional and Equinox Corrections, in IAU Colloq. 63, High-Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations, ed. O. Calame, D. Reidel, 1982.

Won, I. J., and K. H. Son, A Preliminary Comparison of the Magsat Data in the Continental U.S. Geophys. Res. Lett. 9, 4, 296-298, 1982.

Wyatt, F. Distant Deformation for the Imperial Valley, California, Earthquake. Submitted to Bull. Seism. Soc. Amer., 1982.

Wyatt, F., Displacement of Surface Monuments: Horizontal Motion. J. Geophys. Res. 87, 979-989, 1982.

Wyatt, F., K. Beckstrom, and J. Berger, Optical Anchor - A Geophysical Strainmeter. Bull. Seism. Soc. Amer., submitted 1982.

Wyss, M., Some Earthquake Precursors and their Potential Use in the Balkans. Proc. Unesco Seminar on Earthquake Prediction and Instrumentation, Thessaloniki, 1981.

Wyss, M., and M. Baer, Earthquake Hazard in the Hellenic Arc. In Earthquake Prediction - An International Review, Maurice Ewing Series #4, Amer. Geophys. Union, Washington, 153, 172, 1982.

Yanagisawa, M., M. Kono, T. Yukutake, and N. Fukushima, Preliminary Interpretation of Magnetic Anomalies Over Japan and Its Surrounding Area. Geophys. Res. Lett. 9, 4, 322-324, 1982.

Yoder, C. F., and M. A. Slade, The free Librations of the Earth's Inner Core. Geophys. J. Roy. Astron. Soc., submitted, 1982.

Yoder, C. F., J. G. Williams, and M. E. Parke, Tidal Variations in Earth Rotation. J. Geophys. Res. 86, 881-891, 1981.

Yoder, C. F., J. G. Williams, M. E. Parke, and J. O. Dickey, Short-Period Variations in Earth Rotation. Annales de Geophysique 37, 213-217, 1981.

Zanetti, L. J., T. A. Potemra, and M. Sugiura, Elevation of High Latitude Disturbances with Magsat (The Importance of the Magsat Geomagnetic Field Model). Geophys. Res. Lett. 9, 4, 365-368, 1982.

Zanetti, L. J. , and T. A. Potemra, Correlated Birkeland Current Signatures From the Triad and Magsat Magnetic Field Data. Geophys. Res. Lett. 9, 4, 349-352, 1982.

Zhu, S.-Y., Prediction of Earth Rotation and Polar Motion. Dept. Geodetic Science and Surveying Report 320, Ohio State University, 1981.

REFERENCES

NASA, 1980: National Aeronautics and Space Administration, Geodynamics Program Office, Annual Report for 1979: NASA TM 81978, May 1980.

NASA, 1981a: National Aeronautics and Space Administration, Geodynamics Program Office, Annual Report for 1980: NASA TM 84010, October 1981.

ICCG, 1981: Interagency Coordination Committee for Geodynamics, Application of Space Technology to Operational Geodynamic and Geodetic Measurement Services: July 1981.

NASA, 1981b: National Aeronautics and Space Administration, Goddard Space Flight Center, Data Management Plan for Crustal Dynamics Project: H.G. Linder, GSFC X0931-81-18, July 1981.

NASA, 1982: National Aeronautics and Space Administration, Geodynamics Program Office, (Abstracts) Fourth Annual Conference on the NASA Geodynamics Program, January 26-19, 1982.

FIGURE CAPTIONS

1. 1981-California Regional Crustal Deformation Measurements
2. National Crustal Motion Network (NCMN)
3. 1981-Plate Motion and Plate Stability Measurements using VLBI
4. 1981-Plate Motion, Polar Motion, and Universal Time Measurements using Satellite Laser Ranging
5. NOAA Polaris Network
6. Lageos Polar Motion Measurements, May 1976-August 1981
7. Comparison of baselines determined by Lasers and VLBI
8. Magsat Anomaly Map; (a) Z-component (vertical); (b) X-Component (North); (c) Y-component (East)
9. Geopotential Research Mission concept. Satellite-to-satellite tracking antennas protrude above and below the spacecraft. Scalar and vector magnetometers, and star cameras are mounted on the rigid boom on the forward spacecraft.
10. Engineering model of a single axis cryogenic gravity gradiometer. Mounting provisions are included for two additional units which are under construction.

1981 - CALIFORNIA REGIONAL CRUSTAL DEFORMATION MEASUREMENTS

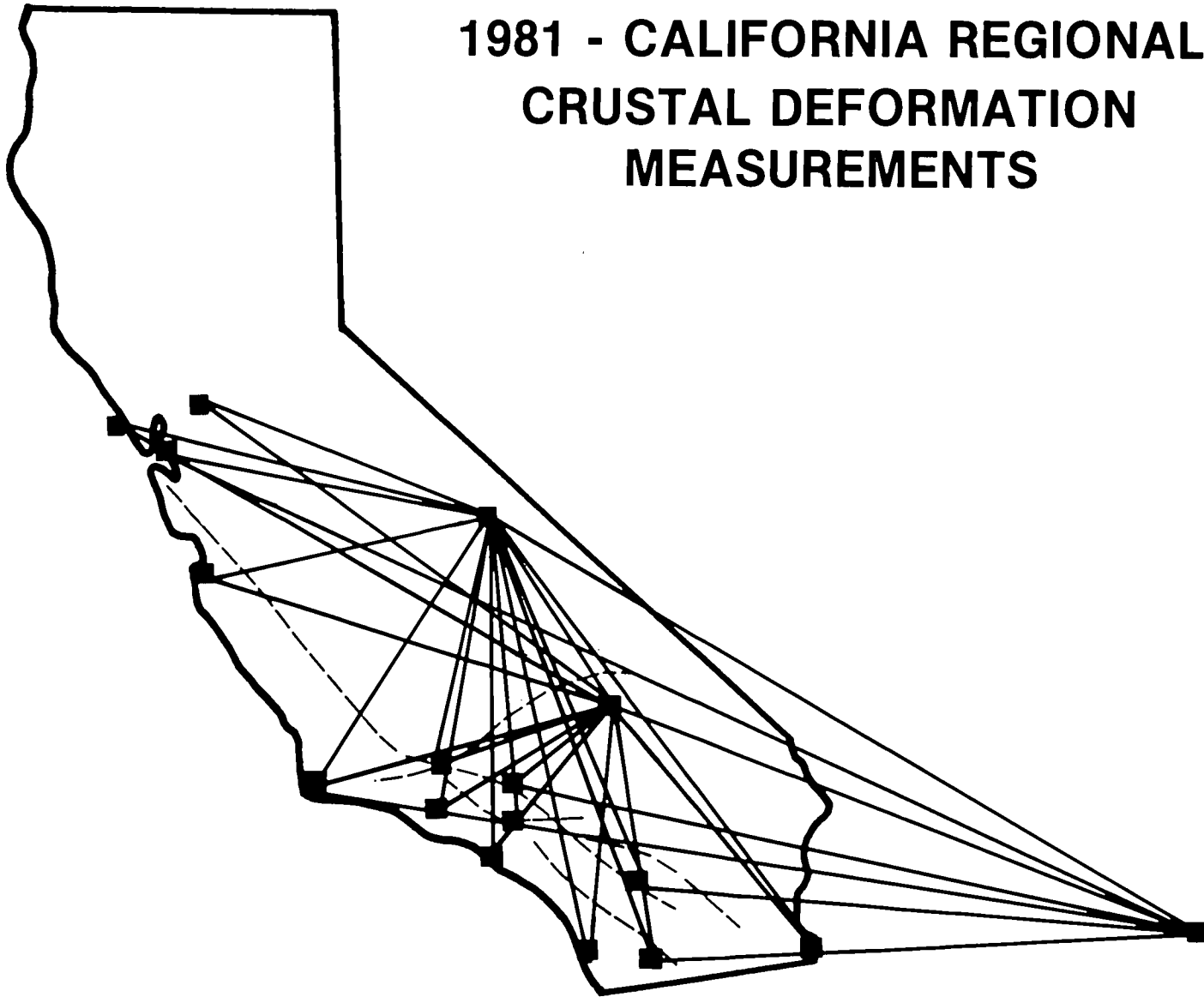


FIGURE 1

NASA HQ EL82-781 (1)
3-5-82

National Crustal Motion Network (NCMN)



FIGURE 2

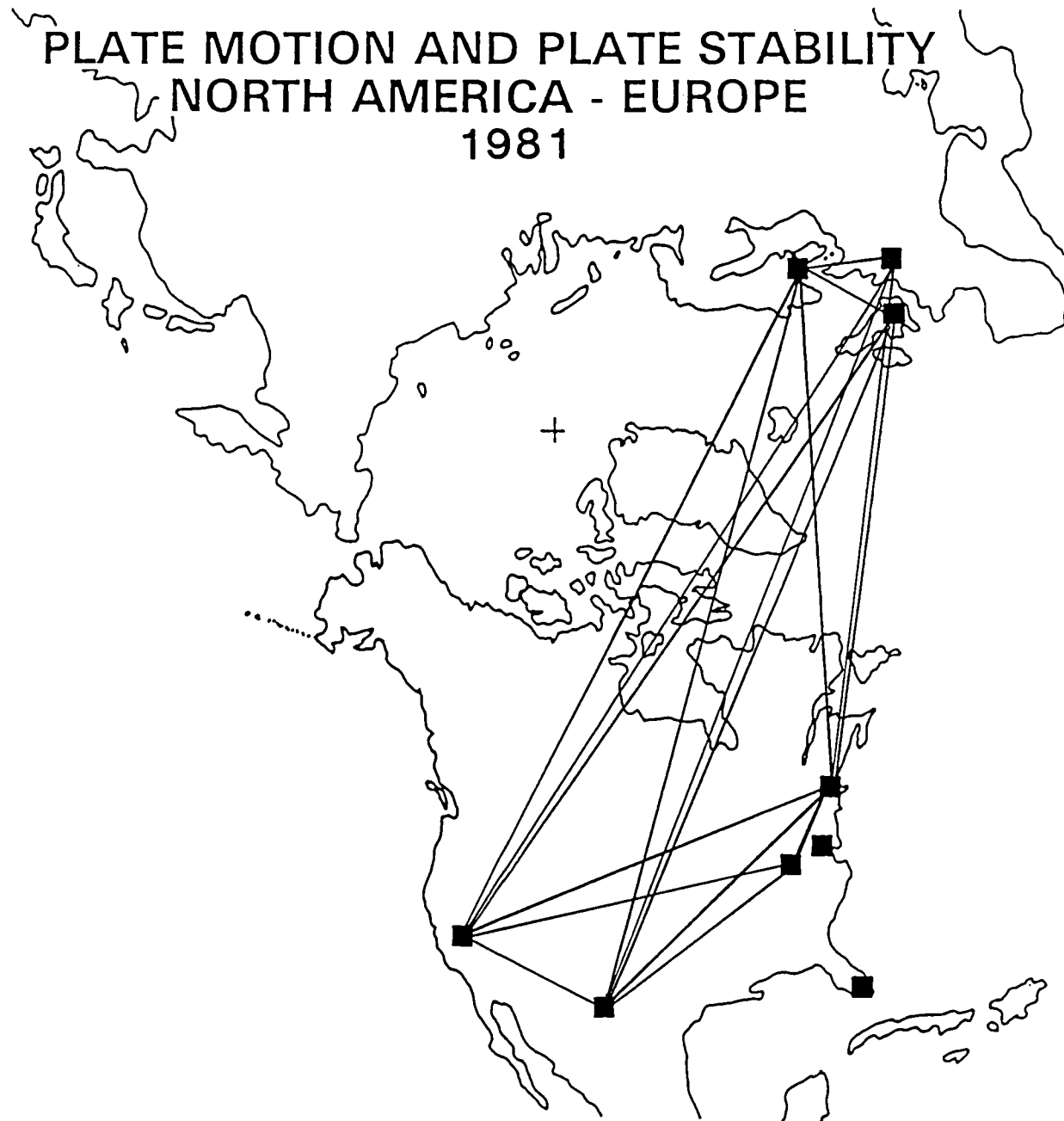


FIGURE 3

PLATE MOTION AND PM/UT 1981

46

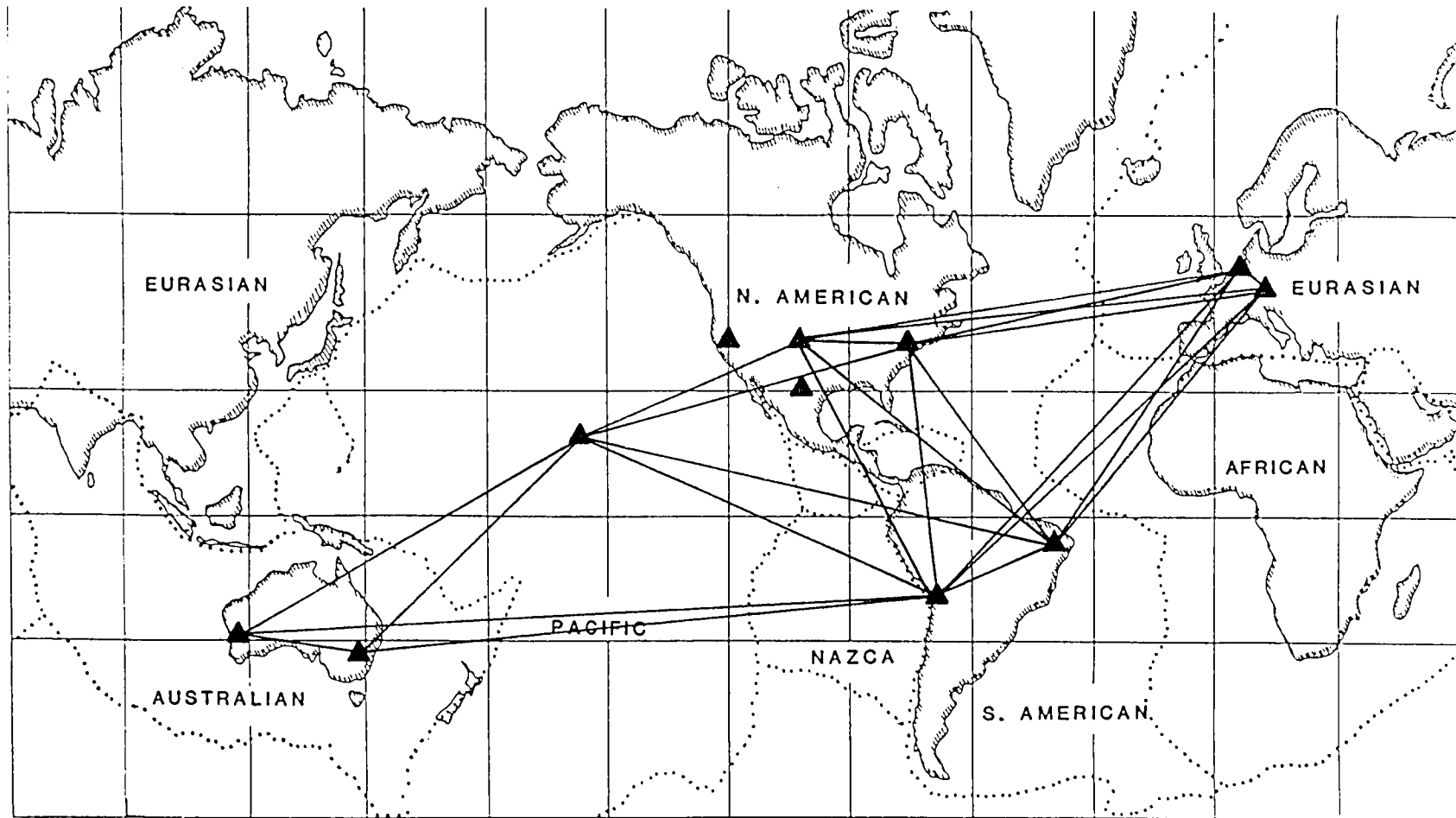


FIGURE 4

POLARIS

47

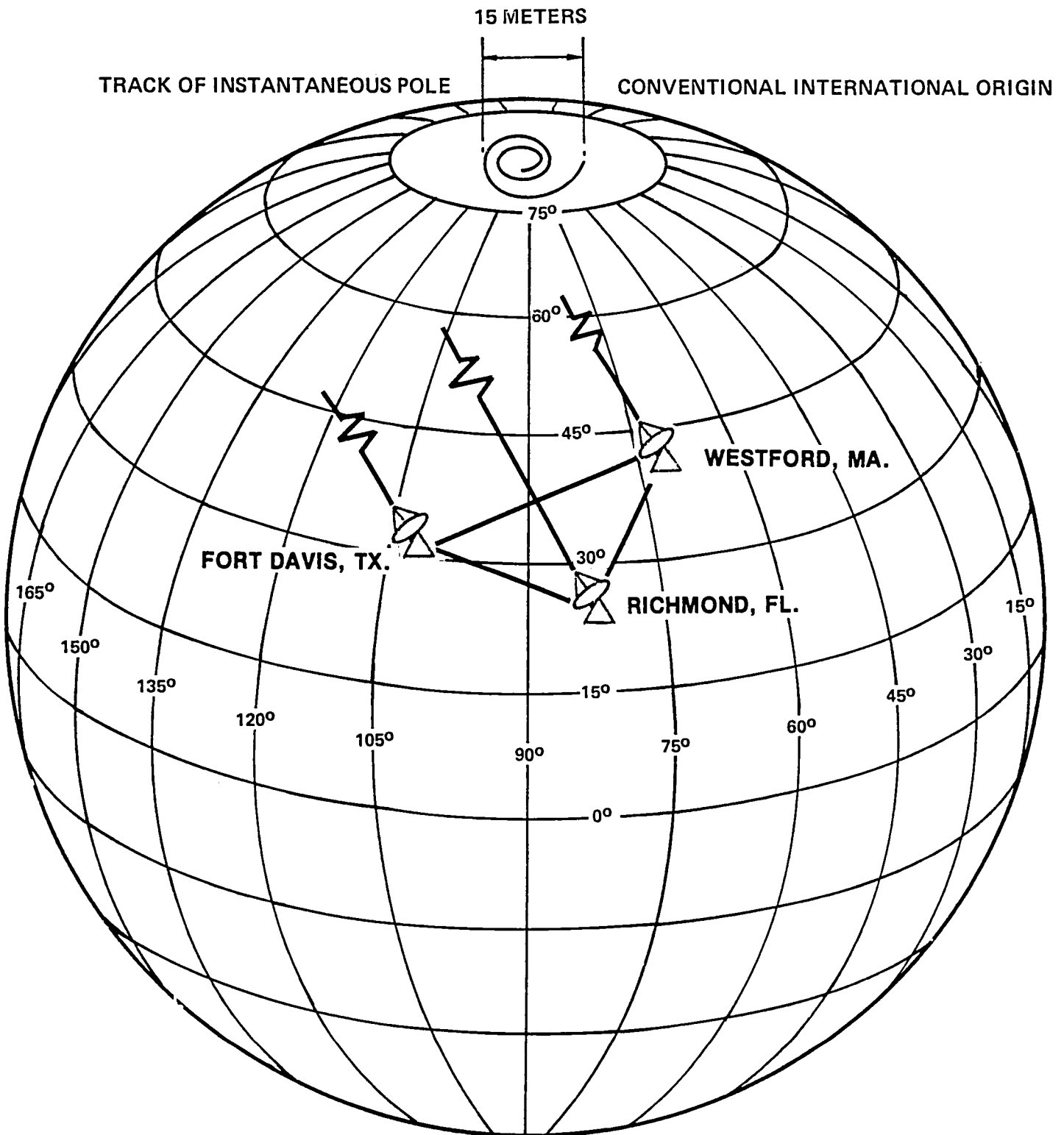
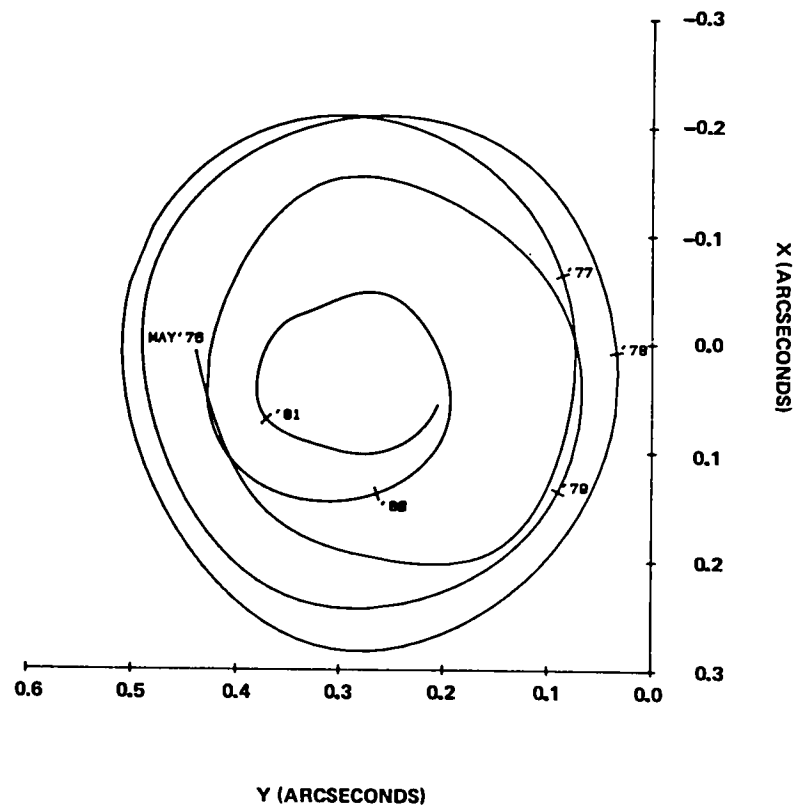
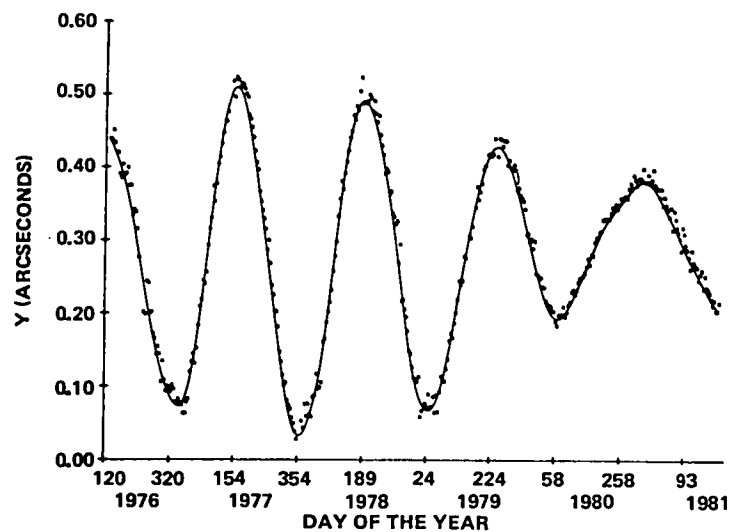
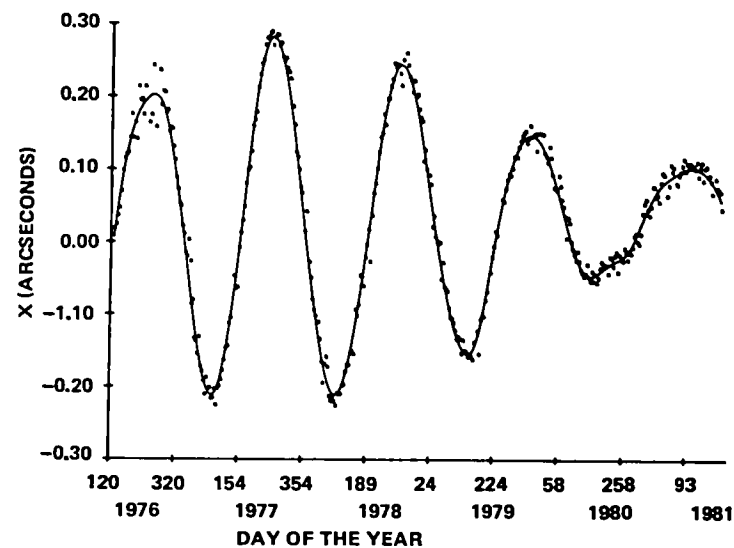


FIGURE 5

LAGEOS POLAR MOTION MEASUREMENTS MAY 1976 - AUGUST 1981



NASA HQ EL82-778 (1)
3-5-82

FIGURE 6

BASELINE DIFFERENCES BETWEEN LASERS AND VLBI

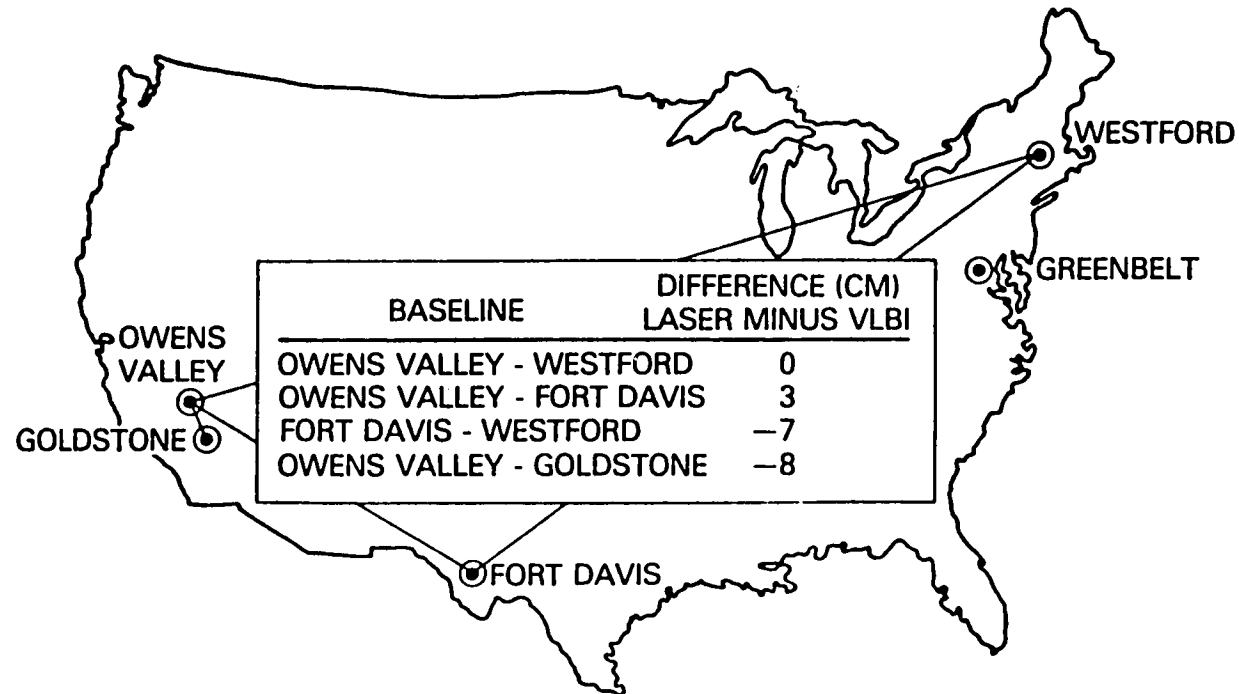


FIGURE 7

MAGSAT ANOMALY MAP

DELTA Z CONTOURS

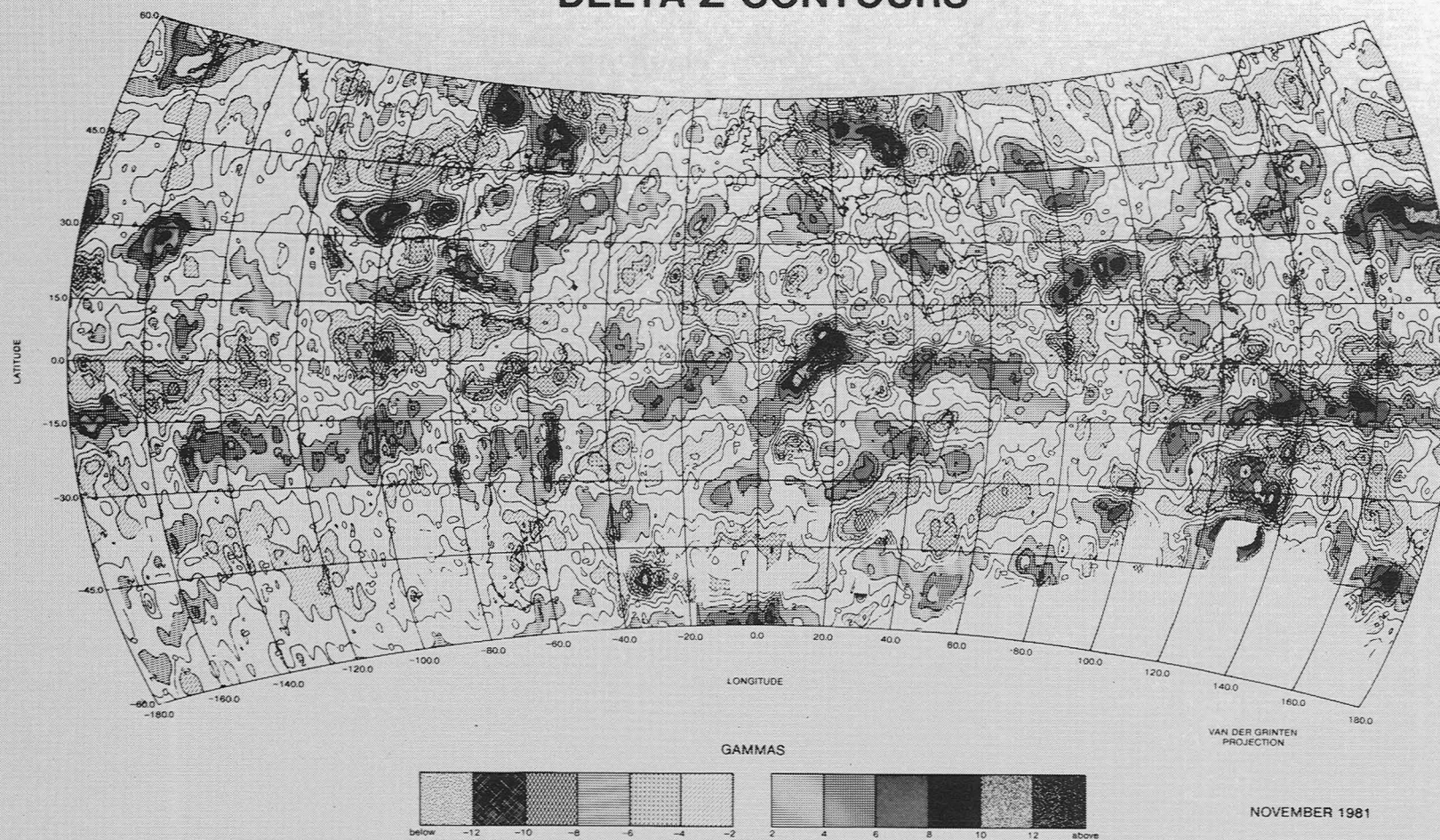


FIGURE 8A

MAGSAT ANOMALY MAP

DELTA X CONTOURS

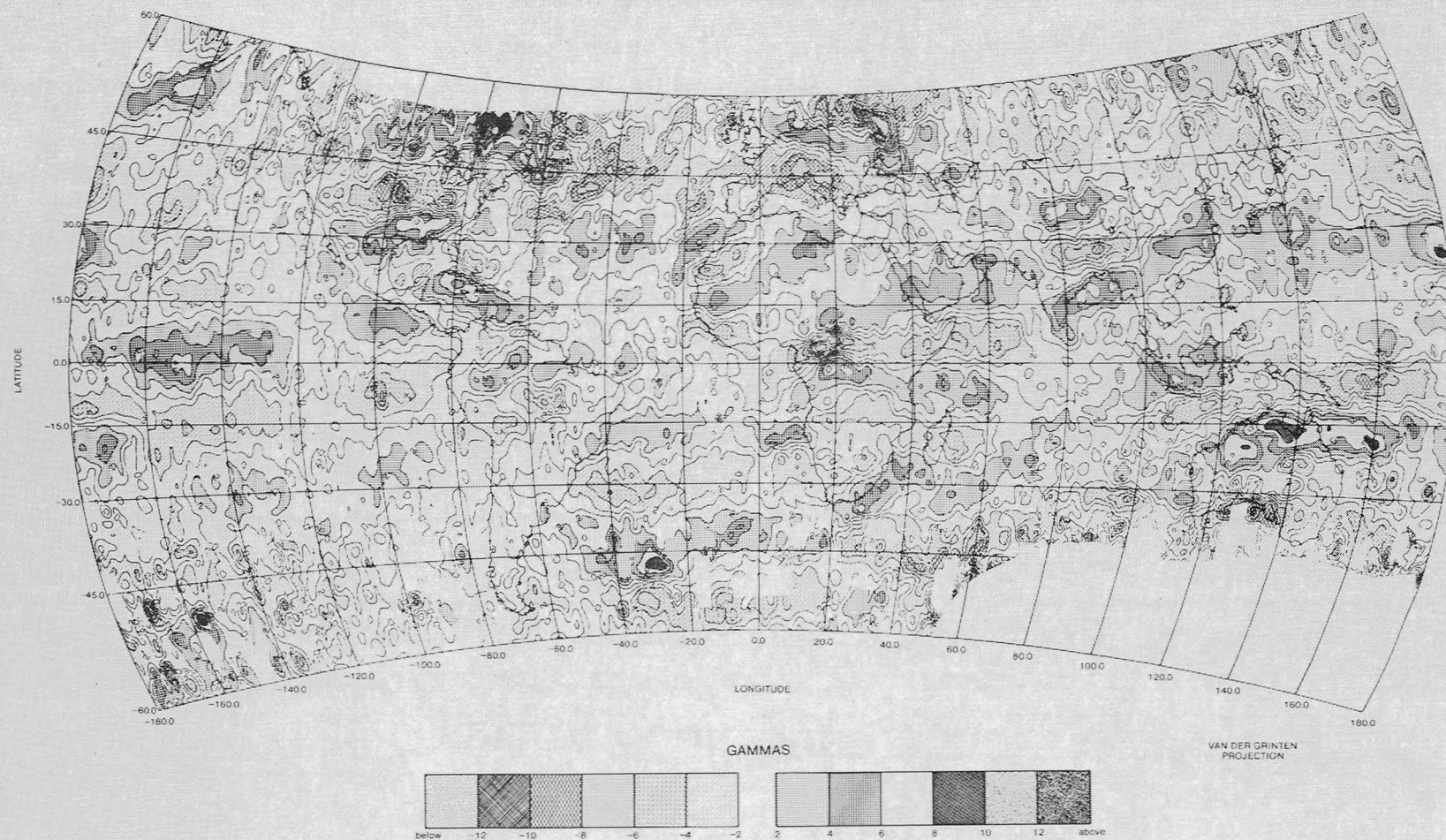


FIGURE 8B

MAGSAT ANOMALY MAP

DELTA Y CONTOURS

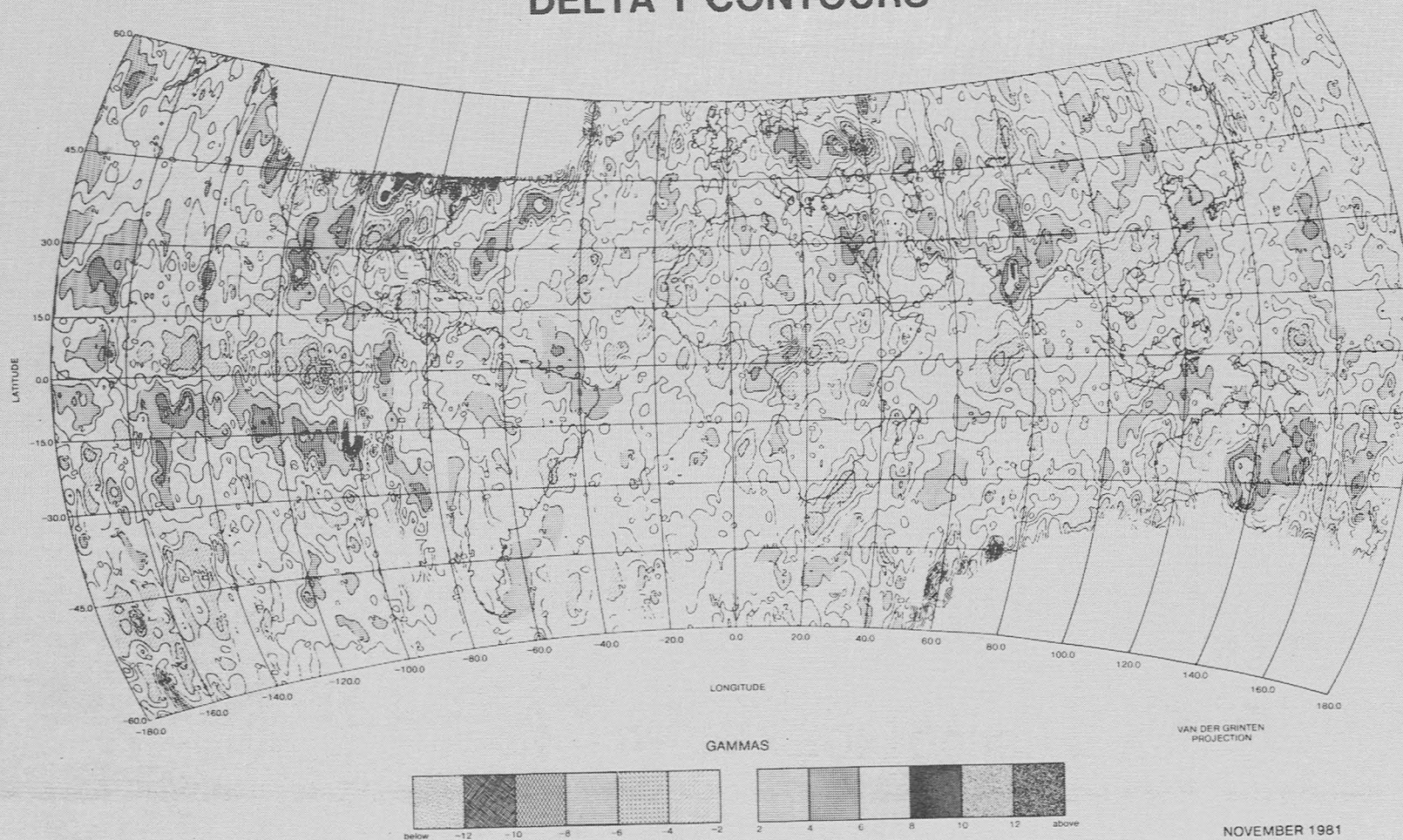


FIGURE 8c

GEOPOTENTIAL RESEARCH MISSION

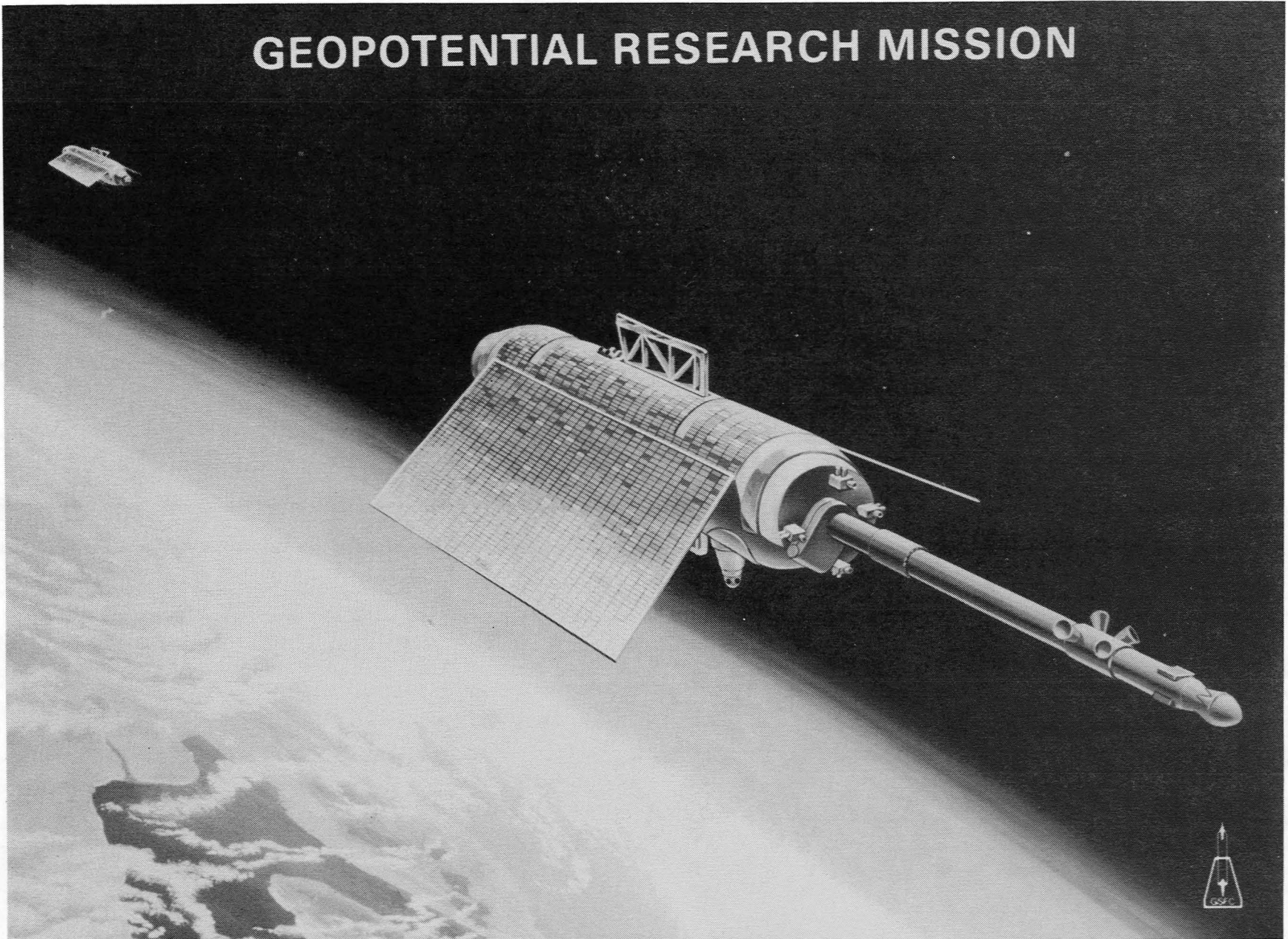


FIGURE 9



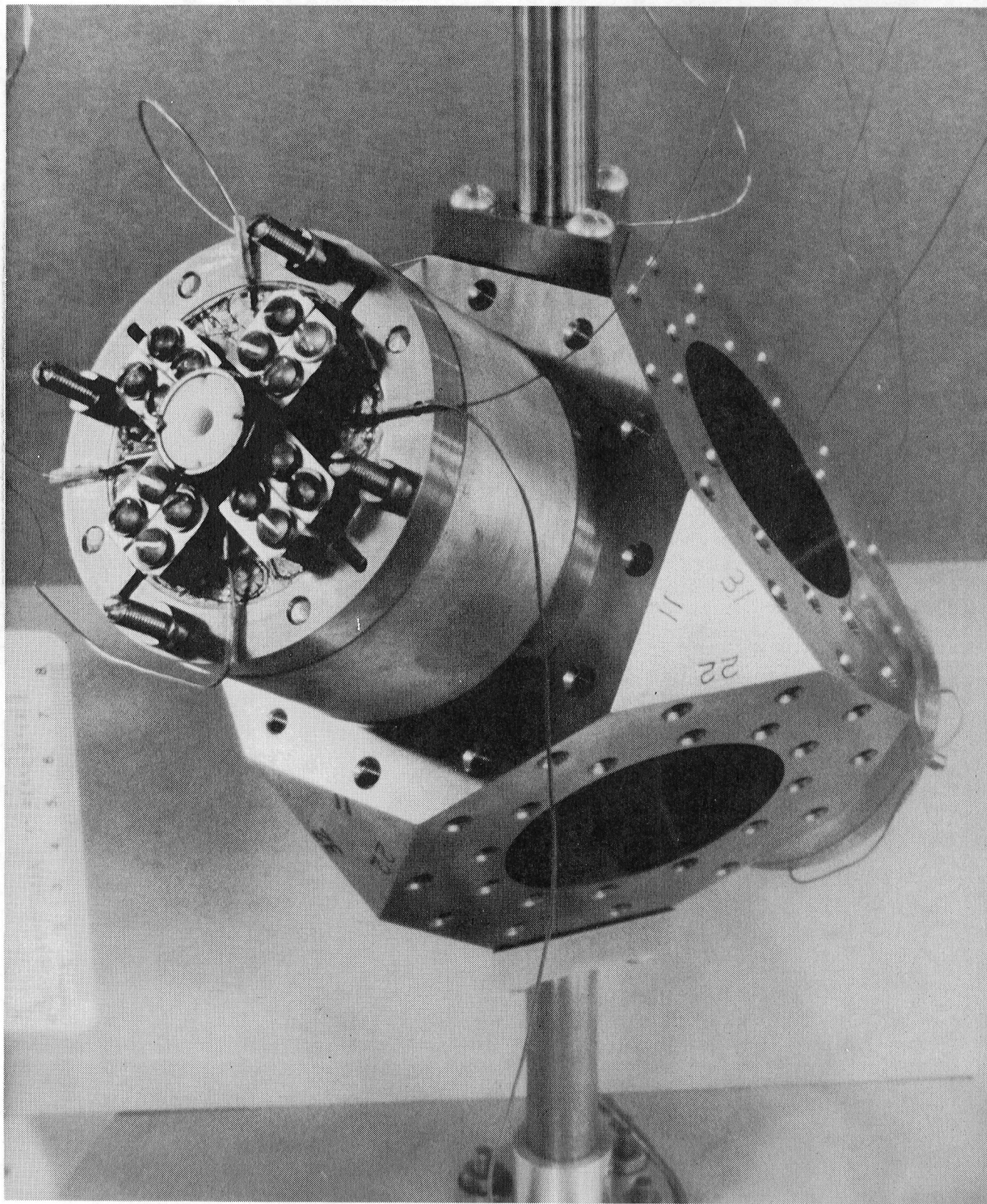


FIGURE 10

| | | | |
|---|--|---|-----------|
| 1. Report No. NASA TM-85126 | 2. Government Accession No. | 3. Recipient's Catalog No. | |
| 4. Title and Subtitle NASA Geodynamics Program: Annual Report for 1981 | | 5. Report Date August 1982 | |
| | | 6. Performing Organization Code EL-4 | |
| 7. Author(s) Geodynamics Program Office | | 8. Performing Organization Report No. | |
| | | 10. Work Unit No. | |
| 9. Performing Organization Name and Address Geodynamics Branch Earth and Planetary Exploration Division Office of Space Science and Applications | | 11. Contract or Grant No. | |
| | | 13. Type of Report and Period Covered Technical Memorandum | |
| 12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546 | | 14. Sponsoring Agency Code | |
| | | | |
| 15. Supplementary Notes | | | |
| 16. Abstract <p>This document is the third annual report of the NASA Geodynamics Program. Its purpose is to inform interested agencies and individuals of the status, progress, and plans of the program. The intention of the Geodynamics Program Office is to issue similar reports each year.</p> <p>The first of these annual reports (NASA TM-81978) contained a section of background and historical information, to bring the reader up to 1979 since the beginning of the program as the National Geodetic Satellite Program. The second annual report (NASA TM-84010) highlighted the progress in instrumentation development and theoretical research, and the preparation for initiation of crustal motion measurements in the western U.S. This report also included a list of publications of research results supported by the Program.</p> <p>This report reflects the progress made in 1981, both in achieving improved measurement precision and in establishing the foundation for the acquisition and analysis of scientific data.</p> <p>The investigations and investigators in the Geodynamics Program and the publications related to the Program are listed in the appendices.</p> | | | |
| 17. Key Words (Suggested by Author(s)) Geodynamics, Geodetic, Crustal Dynamics, Tectonics, Laser Ranging, VLBI, Earthquake, Gravity Field, Magnetic Field | | 18. Distribution Statement Unclassified - Unlimited Subject Category 46 | |
| 19. Security Classif. (of this report) Unclassified | 20. Security Classif. (of this page) Unclassified | 21. No. of Pages 54 | 22. Price |

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business

Penalty for Private Use, \$300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451



NASA

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Return
